

FINAL REPORT

IMPACT OF SECOND HOME DEVELOPMENTS
ON WATER QUALITY IN AREAS OF LOW PRECIPITATION

by

Stanley L. Ponce

and

Jim Dederick

Department of Earth Resources
Colorado State University
Fort Collins, Colorado

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FEB 12 1979

Grant Number 16-659-GR
Eisenhower Consortium #188

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ABSTRACT

IMPACT OF SECOND HOME DEVELOPMENTS ON WATER QUALITY IN AREAS OF LOW PRECIPITATION

The purpose of this study was to quantify the impact of mountain home development on surface water quality in streams draining the east slope of the Northern Colorado Rockies. Selected water quality parameters were sampled from May through September for two consecutive years. Four areas were studied and represented: (a) high housing density (52 homes/km) using septic tanks for sewage disposal on a high flow (80 cfs) stream; (b) moderate housing density (34 homes/km) using septic tanks on a high flow (80 cfs) stream; (c) high housing density (55 homes/km) using septic tanks on a low flow (1-2 cfs) stream; and (d) moderate housing density (32 homes/km) using urban sewage treatment on a low flow (1-2 cfs) stream.

Results indicated only minor degradation of surface water quality on a weekly basis. Suspended solids and primary nutrient concentrations were very similar at both the upstream and downstream sites at each of the four study areas. Indicator bacteria densities varied slightly more than the other parameters, but were still relatively consistent between sampling sites. Fecal coliform to fecal streptococci ratios (FC/FS) were less than 0.7 in almost all instances, suggesting

that livestock and wildlife had a larger influence on the water quality than the developments.

Appreciable increases in suspended solids and indicator bacteria were evident during stormflow. However, these increases were proportional at both the upstream and downstream sites at each study area. The increases in suspended solids concentrations appear to be channel derived. No adverse effects from the road systems at these developments were observed during storm sampling. Bacteriological ratios were all less than 0.7, which suggests that the source of the fecal contamination was not human.

In general, the developments studied do not appear to be affecting the water quality of the nearby streams regardless of housing density or type of sewage facilities utilized.

ACKNOWLEDGEMENT

The authors would like to express their appreciation to the Rocky Mountain Forest and Range Experiment Station, U. S. Forest Service, for support of this study through the Eisenhower Consortium, Grant Number EC 188.

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INTRODUCTION

The east slope of the Colorado Rockies offers a wealth of natural beauty including forests, mountains, streams and lakes. This area borders the Front Range Urban Corridor which contains approximately 80 percent of Colorado's population. Because of their aesthetic value, and close proximity to the large metropolitan areas, the east slope foothills have become increasingly popular for light residential and second home developments. These developments generally center around streams and lakes and appear to blend into the surrounding environment quite well.

These mountain home developments vary considerably in their design. Housing density ranges from very high, with lots of less than one acre in some incorporated communities, to very low, such as one house per five to ten acres. Road systems may or may not be paved, have stabilized side cast slopes, and proper drainage. Sewage treatment may consist of septic tanks and leach fields, outdoor toilets, or collection facilities leading to primary or secondary treatment plants. In most instances, the homes are at or very near the water's edge and represent potential sources of increased sediment and nutrient loads to the stream.

As a result of the Federal Water Pollution Control Act of 1972, the public has become increasingly concerned with the quality of

America's waterways. This law designates that area-wide water quality agencies be developed to establish regional water quality plans. A point of concern to these agencies, as well as to forest managers, is the impact of these mountain home developments on the quality of the surface water draining watersheds of the east slope foothills. This study was initiated in the Spring of 1977 because little work has been done in the past concerning these impacts. The objective of this work was to quantify the impact of second home developments on surface water quality of streams draining the Front Range of the Northern Colorado Rockies.

LITERATURE REVIEW

Light residential and second home developments can cause degradation of water quality in mountainous areas. The problems appear to stem from sewage disposal and road systems rather than direct recreational use. Several studies have shown that recreational uses, such as hiking, picnicking and fishing, have little detrimental impact on the quality of the water resource in mountainous areas (Worms and Brickler, 1967; Brickler and Utter, 1975; Johnson and Middlebrooks, 1975; and Aukerman and Springer, 1976). As a result, this literature review will concentrate on bacteriological, primary nutrient and suspended solids contamination resulting from sewage disposal, site development and road construction. A section reviewing the various types of sewage disposal systems commonly used in these developments will be presented prior to the discussion of pollutional impacts.

Sewage Disposal Systems

Three types of sewage disposal systems are commonly used in recreation home developments. They are outdoor toilets, collection systems and septic tanks, the latter being the most prevalent.

Outdoor Toilets

Outdoor toilets were commonly used with low density mountain housing in the past. In general, these toilets consisted of a wooden enclosure located over an excavated pit utilized for waste containment. This means of sewage disposal worked fairly well in low use areas. Stream pollution problems generally did not occur if the toilet was located a substantial distance from the stream and water table.

Unsealed outdoor toilets are no longer allowed in Colorado. Such systems installed today must have a sealed vault catchment container. As a result, periodic removal of the sewage by pumping is required. This requirement has made this type of system very unattractive to modern mountain home dwellers and has resulted in substantial reduction of its use.

Collection Systems

Sewage treatment by collection systems consists of sewer lines collecting the wastes from a number of homes and routing it to a primary, secondary or tertiary treatment plant. This type of system has its greatest utility in large, concentrated developments surrounding delicate ecological systems. However, development of these sewage systems is restricted in mountain topography due to unstable geologic conditions, rocky soils and steep slopes. In addition, because of the large initial investment coupled with substantial operating costs, the

majority of mountain home developments do not have a centralized system for sewage collection and treatment.

Septic Tanks

Septic tanks are the most widely used type of sewage disposal system in mountain developments of Colorado. The operation of the septic tank is relatively inexpensive and actually quite simple. Sewage flows into the holding tank where the heavier particles, commonly referred to as sludge, settle to the bottom, while the lighter particles, or scum, float on the water. Anaerobic bacteria in the tank decompose the solid particles, along with the dissolved organics in the water, to various gases and water. The more resistant material accumulates in the bottom of the tank and must be removed periodically. Removal of 50 percent of the biochemical oxygen demand (BOD) and 70 percent of the suspended solids can be expected if the system is operating properly. The effluent from the septic tank then flows to an adjacent leach field. In general, the pathogenic organisms and the remaining BOD will be removed within 30 meters of the leach field. However, if these systems are not designed and maintained properly, they can contaminate adjacent water supplies resulting in a public health hazard and may cause eutrophication of downstream lakes, ponds and reservoirs.

Existing soil conditions play a major role in determining the location and efficiency of a septic tank. Such physical characteristics

as soil depth, slope, texture, and hydraulic conductivity have to be considered (Orlob and Krone, 1956; Romero, 1970). Effluent from the septic tank is discharged into the soil by means of a seepage pit, bed, or trench. Cain and Beatty (1965) note that the rate at which the soil absorbs the effluent is critical to the efficiency of the sewage disposal system. If the effluent is not absorbed rapidly enough, it may back up into the drains in the home and eventually it may rise to the surface of the ground over the seepage area. If the effluent drains through the soil too rapidly, it may travel unfiltered into wells or surface water supplies and contaminate them with water rich in nutrients and various types of disease-bearing organisms.

Burns et al. (1973) attempted to establish the relationship between the geologic setting and the occurrence of water pollution at mountain home developments containing individual sewage disposal systems. They determined that leach field areas should be a minimum of 30 meters from rivers, streams, lakes and wells in order to minimize the probability of polluting surface water supplies. Franks (1971) lists the following causes of failure of leach field systems:

- 1) construction of leach field systems on slopes exceeding 20 percent,
- 2) location of leach field systems near construction cuts such that there is less than 5 meters of soil horizontally between the ground surface and the bottom of the leaching system,

- 3) construction of leach field systems in open gravel areas with a high water table,
- 4) construction of leach field systems on bedrock fractures which do not provide adequate filtration or treatment of effluent, and
- 5) construction in surficial pervious deposits over non-water bearing rocks which may result in downstream surfacing of fluid.

Few studies have been reported that relate surface and ground water quality to mountain home developments. However, various water pollutants may originate from such developments. These include indicator bacteria, primary nutrients and suspended solids. The balance of this literature review will therefore be concerned with interpretation, source and movement of these constituents in mountainous areas. It is believed that this approach will enable a more thorough interpretation to be made of the cause-effect relationship investigated in this study.

Bacterial Contamination

As a consequence of increased recreational demands on Colorado's upland watersheds, including mountain home developments, a growing concern of land managers has been disease transmission resulting from fecal pollution occurring in these waters. The

intestinal wastes from warm-blooded animals, including man, regularly comprise a wide variety of genera and species of bacteria, viruses and protozoa, some of which are pathogenic to man. Because the number of pathogenic organisms is generally quite low and they are often difficult to isolate, microbiologists developed the "indicator organism" technique for confirming the presence of fecal pollution.

Dutka (1973) writes that an indicator organism of feces-oriented water pollution should:

- 1) be applicable in all types of fresh water,
- 2) be present and occur in much greater numbers than the pathogens concerned,
- 3) not be able to proliferate to any greater extent than enteric pathogens in the aqueous environment,
- 4) be more resistant to disinfectants and to the aqueous environment than the pathogens,
- 5) disappear rapidly from water following the disappearance of pathogens and be absent in bacteriologically safe water,
- 6) lend itself to routine quantitative testing procedures without interference or confusion of results due to extraneous bacteria, and
- 7) be harmless to man and other animals.

It was discovered that the presence of fecal coliform and fecal streptococcus bacteria in water specifically indicates fecal waste

contamination by warm-blooded animals (Millipore Corporation, 1973).

The occurrence of fecal coliform bacteria in water is regarded as the single most important indicator of public health hazard from infectious agents (McFeters and Stuart, 1972). Members of the species Escherichia coli (E. coli) were found to be the typical variety of fecal coliform bacteria, with lesser numbers of Anterobacter aerogenes present. The Enterococci group of the genus Streptococcus are the characteristic variety of fecal streptococcus bacteria (Kunkle, 1965).

Exceedingly high concentrations of coliform organisms have been reported for mountain developments in Colorado. Millon (1970) reports that 62 percent of the wells used for domestic water supplies at Red Feather Lakes, Colorado were found to be polluted, with coliform counts of 500 colonies/100 ml observed in some instances. At the Manitou Experimental Forest near Woodland Park, Colorado Ponce et al. (1977) observed coliform counts as high as 260 colonies/100 ml during routine streamflow and counts exceeding 7000 colonies/100 ml during stormflow.

Morrison and Fair (1966), after studying a stream having no known pollution from domestic sewage, concluded that runoff from the surrounding watershed was the most important source of bacterial contamination. They reported a marked seasonal variation in coliform counts, with peak values being observed in October, February, and August.

Voelker et al. (1960) conclude that season of the year is a major factor controlling bacterial content of the water. In their study, they found that high bacterial counts were typical of the warmer months, with densities decreasing through the fall to minimum values about January, followed by a steady climb through the spring. Van Donsel et al. (1967) noted that the fecal coliform survived slightly longer than the fecal streptococci during the summer. Survival rates were nearly equal during autumn, and in spring and winter the fecal streptococci survived much longer than the fecal coliform. In their 1967 study, Kunkle and Meiman report that high counts of fecal coliform and fecal streptococci appeared during the rising and peak flows caused by June snowmelt and rain. A short "post flush" lull in counts took place as runoff receded in July. High counts were again found in the July-August period of warmer temperatures and low flows, with a gradual decline in counts in September. In general, fecal coliform and fecal streptococci counts ranged from 0 to 75 colonies/100 ml during normal flow. Skinner et al. (1974) monitored the water quality of a mountain watershed during the summers of 1970-1972. They found that in 11 out of 17 cases, fecal coliform counts increased 10 to 100-fold in concentration in July or August over values obtained in June or September, and that maximum numbers of fecal streptococci were usually seen at all sample sites in July or August.

Walter and Bottman (1967) found that, in general, the microbial population increases as the water moves downstream and receives melting snow and runoff from many tributaries.

Large increases in densities of coliform bacteria in streams usually follow periods of rainfall that result in significant surface runoff to the streams (Kittrell and Furfari, 1963). Morrison and Fair (1966) state that the addition of bacteria to the stream from the land surfaces of the watershed during short duration summer rainstorms was the most important cause of variation in bacterial numbers in the stream they studied. Van Donsel et al. (1969) suggest that under non-freezing conditions, an increase in fecal coliforms would occur after a rainfall. They state that the magnitude of the increase would not be proportional to the amount of rain, but instead would be related to the temperature conditions following the rainfall.

Kunkle and Meiman (1968) report very high bacteria counts occurred during summer storm stage rises but counts on receding limits of these hydrographs were comparable to pre-storm values, or even lower. They concluded from all of their observations of storms that "flushing" by rising stages increases bacteria counts. Fecal coliforms rose to four times and fecal streptococci to eight times the pre-storm value.

Geldreich (1967) reports that analysis of data collected over a two-day period indicated the fecal coliform tracer organism could be

isolated from stormwater runoff with the greatest regularity in the springtime, during periods of heavy rainfall which lasted up to 10 days. He further concluded that once the soil dried out after prolonged rains, subsequent showers failed to produce significant numbers of the tracer organism.

Geldreich et al. (1968) found that fecal streptococcus densities were consistently higher than fecal coliform levels during stormwater runoff. Geldreich and Kenner obtained similar results in their 1969 study. They also demonstrated the possible existence of summer and winter peaks in bacterial indicator densities in drainage from rural stormwater runoff.

Coliform interactions with soil are important in determining bacterial pollution. Generally, the higher the soil moisture content, the higher the coliform counts tend to be. However, an exception to this was demonstrated by Van Donsel et al. (1967). Under subfreezing conditions, when the soil moisture content was very high (above 35 percent) and was caused by frost or snow, a decrease in coliform numbers was recorded. Repeated freezing and thawing caused significant mortality of E. coli.

In his study, Smith (1975) constructed a physical model of subsurface flow through glacially-derived soils. Escherichia coli were in no case detected after 3 m of travel through relatively pervious soils under a 10 percent gradient. An initial progression and

subsequent retreat of bacterial pollution was observed over a seven-day period of continued influx. He attributed this to a combination of interface clogging and attenuation in the soil.

Butler et al. (1954) conclude that the removal of bacteria from liquid percolating through a given depth of soil is inversely proportional to the particle size of the soil. Baars (1957) states that unless accompanied by a considerable quantity of water, bacterial contamination will not penetrate far in sandy soils. If the ground water level is high, however, contaminants which have once reached the groundwater may stay there practically unchanged for a long time.

Petersen and Boring (1960) suggest that the source of E. coli and other coliforms might be contaminated soil or mud rather than fresh fecal material. This is supported by several investigations on the viability of the organisms in soil as compared by Rudolfs et al. (1950).

In general, groundwater and stream contamination results when the soil media is overloaded with effluent, which produces an inadequate residence time for oxidation of organic material, uptake of nutrients by vegetation, and removal of bacteria (Ponce et al., 1977).

Primary Nutrients

Primary nutrients, such as nitrate-nitrogen and orthophosphate are often associated with sewage wastes from septic tanks. The

major problem resulting from these nutrients is eutrophication or a stimulation of the growth of algae and other aquatic plants in both flowing and impounded surface water supplies.

Nutrient loading often increases with erosion, through such processes as adsorption to soil particles. Grant and Lewis (1975) found that nutrient concentration increased in a small stream below a construction site near Boulder, Colorado, and attributed the increase to the removal of vegetation and accelerated erosion on the site.

Nitrification occurs at a relatively slow rate in cold water, and hence nitrates are not normally a serious problem in most mountain waters unless an effluent which has undergone some nitrification during treatment is discharged into a small receiving stream (Flack, 1976).

McCarty et al. (1967) state that the major forms of nitrogen that serve as nutrients are ammonia nitrogen ($\text{NH}_3\text{-N}$), nitrite nitrogen ($\text{NO}_2\text{-N}$) and nitrate nitrogen ($\text{NO}_3\text{-N}$). All these forms are water soluble and can be readily used for plant growth. He also reports that nitrate nitrogen moves rather rapidly through the soil with the drainage water and is influenced primarily by biologic factors.

Segall (1975) concludes, however, that long travel distances through soil are required to deplete nitrogen concentrations. The primary sources of nitrogen in domestic waste water are feces, urine, and waste food.

McCarty et al. (1967) report that the form of phosphate occurring in natural waters is pH dependent, and by far the major amount of phosphorus in the earth's crust is represented by one mineral family, the apatites. Many phosphate-containing minerals are only slightly soluble in water and this tends to limit the concentrations found in natural waters. Phosphate in domestic sewage results from the following sources: (1) human wastes; (2) built detergents; (3) carriage wastes; and (4) infiltration waters.

Baker et al. (1975) report that water containing surface drainage can have orthophosphate ($\text{PO}_4\text{-P}$) concentrations much greater than subsurface drainage water. Hanway and Laflen (1974) found an average of 0.65 mg/l $\text{PO}_4\text{-P}$ in surface drainage relative to 0.11 mg/l in subsurface drainage.

In his 1976 study, Segall examined the impact of recreational developments on water quality of streams in northern Arizona. He reported total nitrogen levels ranging from less than 1 to 1 mg/l while phosphate ranged from 0.1 to 0.7 mg/l. Flack (1976) reports that stream orthophosphate concentrations as high as 0.2 mg/l should not cause undesirable enrichment.

McCarty et al. (1967) conclude that, in general, it can be expected that drainage losses from a soil will be much greater for nitrate and other nitrogen forms than for phosphate.

Suspended Solids

Increased suspended solids concentrations may also be related to mountain homesites. The U.S.E.P.A. (1973) reports that sediment is the most prevalent water pollutant associated with recreational home development.

A site is prepared for home construction by being cleared of vegetation and graded. Removal of vegetation exposes the soil, thus making it more susceptible to erosion. Consequently, if vegetative cover is not quickly reestablished and the soil grade at the site is not stabilized, a serious erosion problem may result. Vice et al. (1968) report that of the 33,500 metric tons of suspended solids yielded from a Virginia watershed over a four-year period, 94 percent was directly related to construction activity occurring on just six percent of the total basin area. This sediment release was attributed to the composite effect of vegetation removal, soil disturbance and consequent increased runoff.

Traditionally, roads have been considered to be a primary source of sediment to upland streams. Road cuts and fills, stream crossings and the road surface itself are all potential sources of suspended materials (Howe, 1972). Road construction and site compaction causing increased runoff may result in ditch scouring and an increase in stream channel erosion.

Ponce et al. (1977) found that streams associated with a development having a poorly designed road network had greater concentrations of suspended sediment than did those streams flowing through a development with a good road network design. They concluded that the magnitude of impact appears to be a function of construction practices.

Flack (1976) concludes that considerable increases in suspended solids in the spring in many mountain developments is a direct result of snowmelt runoff. Swenson (1964) observed that 90 percent of a stream's annual sediment load may charge in 10-12 days and as much as one half of the year's sediment load may occur in one storm.

Ponce et al. (1977) found significant increases in suspended solids following the occurrence of convective rainstorms in the Manitou Experimental Forest.

Barton (1951) reports, however, that discharge volume does not explain all the variations of suspended sediment volume. Much of the variation not explainable by stream discharge was assumed to be due to:

- 1) Intensity and amount of precipitation,
- 2) Vegetal cover,
- 3) Season of year,
- 4) Topography,
- 5) Size of stream,
- 6) Condition and kind of surface soil,

7) Stability of channel, and

8) Intensity of land use.

It is readily apparent that recreational home developments are potential sources of sediments to adjacent streams and lakes when the large number of roads, along with site disturbance for dwellings is considered.

METHODS AND PROCEDURES

Study Area

The study area selected is located in the montane life zone of the Front Range of the Colorado Rockies and lies about 65 km west and 90 km southwest of Fort Collins, Colorado (Figure 1).

Local Characteristics

The summers are normally cool while the winters are cold and dry. The mean annual temperature range for July is 4 to 78 C and -11 to 4 C for January. The total annual precipitation normally ranges from 400 to 640 mm with March, April and May traditionally being the wettest months. Rainstorms during the summer months are usually of a convective origin and occur as afternoon and evening thunderstorms. Snow is the major form of precipitation from October to April.

The study area consists of a wide variety of metamorphic and granitic rocks, which are complexly faulted. All of the streams within the area originate in and flow through the Silver Plume Granite formation of Precambrian Age. Soils derived from this rock type are weakly developed, coarse textured, highly permeable and readily erodible when the vegetative cover is removed. In general, the soils are shallow on the upslope and increase in depth near the valley

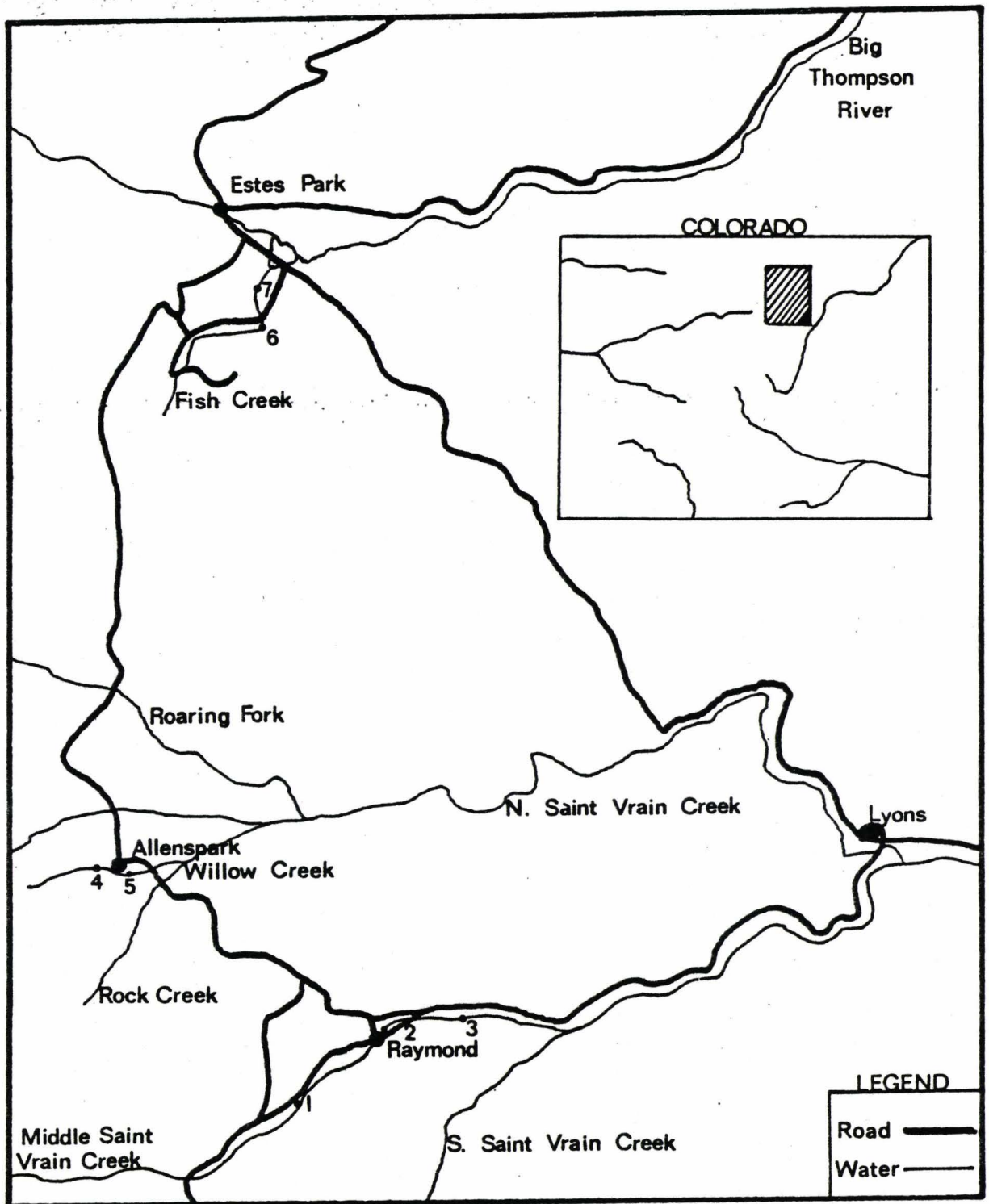


Figure 1. Study area and sampling stations.

bottom where alluvium is prevalent. The alluvial soils are more finely textured and less permeable.

The overstory vegetative cover is primarily ponderosa pine, intermingled with quaking aspen, Douglas-fir, Colorado blue spruce and Englemann spruce. There is little or no underbrush growth. Willow, thin leaf alder, water birch and common chokecherry are the dominant woody plants along stream channels.

The majority of the study area lies within Roosevelt National Forest. However, the mountain home developments are situated on private holdings within the National Forest. The major land uses are hiking, fishing and hunting.

Treatment Descriptions and Site Locations

Four treatments to be examined by this study were established. Criteria for treatment design were stream discharge, housing density and means of sewage treatment. Sampling sites were located above and below each treatment.

Treatments I and II

Sites 1, 2 and 3 (Figure 1) are situated near Raymond, Colorado and lie on the middle fork of the St. Vrain River, a relatively high flow mountain stream. Treatment I was located between sites 1 and 2 and contained a 1.8 km stream reach. Site 1 had an elevation above mean sea level of 2390 m while site 2 was 2347 m. This treatment

represented high stream flow (average discharge for the study period was 80.0 cfs), heavy housing density (52 homes/km of stream) and had septic tanks for sewage disposal. In general, the houses, 67 in all, were located within 30 m of the stream channel.

Treatment II lies immediately downstream from Treatment I. It was bounded by sites 2 and 3 (Figure 1), and contains a 3.6 km reach of stream. Site 3 had an elevation of 2188 m. This treatment represents high stream flow, moderate housing density (34 homes/km of stream) and had sewage treatment similar to Treatment I.

Treatment III

Treatment III was located within Allenspark, Colorado (Figure 1). It was situated along a 1.4 km stretch of Willow Creek and was bounded by sites 4 and 5. Site 4 was located above site 5 with elevations of 2585 m and 2542 m, respectively. This treatment represents low streamflow (average discharge during the study was 1-2 cfs), heavy housing density (55 homes/km of stream) and sewage treatment by septic tanks.

Treatment IV

Treatment IV was located on a 1.0 km section of Fish Creek near Estes Park, Colorado. It was bounded by sites 6 and 7 which had elevations of 2338 m and 2310 m, respectively. This treatment represented low flow (average discharge during the study was 1-2 cfs),

moderate housing density (32 homes/km of stream) and sewage treatment by a collection system leading to a secondary sewage treatment plant.

Parameters Sampled and Methods of Determination

Discharge

Discharge was measured by the velocity-area method using a March-McBirney model 201 direct reading current meter. Depths were measured simultaneously with the velocities at 0.30 m intervals across the width of the stream.

Discharge for storm events was determined by the rating curve method. Stream depth was observed on staff gauges established near the sampling cross section.

Physical Parameters

Suspended Solids. Suspended solids were measured in the laboratory following the procedures outlined in Standard Methods (American Public Health Association (A.P.H.A.), 1971). A 100 ml volume of a well shaken sample was passed through a Whatman GF/C glass microfibre filter. After drying in the oven at 103-105°C for 24 hours, the increase in weight over that of the empty filter was determined.

Chemical Parameters

Chlorides. Chlorides were determined in the laboratory using the Argentometric Method (A.P.H.A., 1971). Prior to titration with 0.014 N. Silver Nitrate Standard solution, 1 ml of Potassium Dichromate indicator solution was added to the 100 ml sample.

Nitrate-Nitrogen. Nitrate-nitrogen was determined in the laboratory using the Hach modification of the Cadmium Reduction Method (Hach Chemical Company, 1975). Absorbance readings were taken on the Bausch and Lomb Spectronic 70 spectrophotometer. Concentration of nitrate-nitrogen was determined from a standard curve. A new standard curve was developed for each new batch of Hach powder pillows.

Orthophosphate. Orthophosphate concentrations were measured in the laboratory using the Murphy-Riley Technique (Strickland and Parsons, 1968). Absorbance was measured on a spectrophotometer (Bausch and Lomb Spectronic 70) and the concentration determined from a standard curve. A new standard curve was developed each time a new liter of Armstrong Reagent was made.

Biological Parameters

Fecal coliform and fecal streptococci were determined in the laboratory using the membrane filter technique. All glassware, funnels, buffer water, tweezer, and media used in the procedure were sterilized in an autoclave prior to sample collection and

filtration. Two sample volumes, 100 ml and 10 ml, were utilized for each of the indicator organism determinations except during storm sampling, when several different volumes were used. Fecal coliforms were incubated in a water bath at $44 \pm 0.2^{\circ}\text{C}$ for 24 hours while the fecal streptococci were placed in an air incubator at $35 \pm 0.5^{\circ}\text{C}$ for 48 hours. Organism counts were made with the aid of a light microscope.

Sample Collection

Grab samples for the chemical parameter analysis were taken in 1000 ml Nalgene bottles while samples for biological analysis were taken in sterilized 250 ml BOD glass bottles. Samples were collected at midstream and depth integrated. Samples were stored in a styro-foam cooler and were transported to Colorado State University and placed in a refrigerator as soon as possible. The biological analyses were performed upon returning to the laboratory, with the remainder of the chemical analyses being done within 24 hours of collection.

Sampling Frequency

Diurnals

A diurnal sampling was performed at each treatment area early in the study. The purpose of this 24 hour examination was to determine if composite sampling would be required during the routine

sample collection. Samples were collected every three hours during this test beginning at 0900 hrs.

Routine

Routine samples were collected each Sunday, beginning in late May and continuing through August during 1977 and 1978. Thereafter, samples were collected every two weeks, again on Sundays, through September. To promote sampling consistency, samples were taken at nearly the same time of day each week. The sites were sampled in the fixed order of 3, 2, 1, 5, 4, 6 and 7 (Figure 1).

Storm

Two different types of storms, frontal and convective, were monitored at the various treatment areas. A frontal event lasting six hours was sampled on 3 August 1978 at Treatments I (sites 1 and 2) and II (sites 2 and 3), with samples collected every hour. Two convective storms of thirty minutes or less were measured on 27 July 1978 and 25 August 1978 at Treatment III (sites 4 and 5). Two separate convective storms of similar duration were monitored at Treatment IV (sites 6 and 7). The first occurred on 27 July 1978 and the second on 26 August 1978. Samples for these convective events were taken simultaneously at each site every 10 minutes.

Statistical Analysis

The data collected were analyzed statistically in four different phases. Phase one used the data collected on six weekly sampling dates (11, 18, and 25 June and 6, 13, and 20 August, 1978). Two samples were taken at each site (replicate sampling) and the field parameters determined from them. Upon return to the laboratory, these samples were split in half, making a total of four sample volumes, from which the laboratory parameters were then determined (split sampling). The purpose of this replicate sampling and subsequent sample splitting was to determine how much of the variance in the parameters was due to analytical technique and methods used. An analysis of variance technique to partition the sources of sampling error was performed on the data. Variance due to the actual replication and splitting of the samples was tested. A significance level of less than or equal to 10 percent ($\alpha \leq 0.10$) was used in this test, with the test statistic taking on an F value.

The second phase of the statistical analysis dealt with the data obtained during the diurnal sampling. Ninety-five percent confidence intervals were constructed for each parameter at both sites for each treatment. Mean values, along with a "Z" value (normality was assumed) and standard errors, were used in the computation of the confidence intervals. This was done to test for pronounced diurnal

fluctuations and to specify if composite sampling during the routine collection was required.

In phase three, the data collected routinely was analyzed by use of a two-way analysis of variance procedure, comparing site versus date. Variation within a given treatment, which is the difference between the upstream and downstream sites, was tested. Also, variances between treatments were analyzed, paying particular attention to differences in housing density, streamflow, and sewage facilities employed. Significant differences of $\alpha \leq 0.10$ were recorded as "significance of F."

The fourth phase was concerned with the rainstorm data. Mean values of the parameters were compared to those means obtained during routine sampling. The analysis of variance was run on these data as the values for the parameters increased proportionately at both the upstream and downstream sites during the storm events.

RESULTS AND DISCUSSION

The results of this study are presented and discussed in four separate sections. The first section presents the results of the ANOVA designed to examine sampling error. The second section examines the results of the diurnal test while the third section examines the routine weekly sampling results. The fourth, and final, section is a discussion of the results obtained from rainstorms.

Because of the large amount of data collected during the study, it would be impractical to include all of it in this paper. Therefore, the data has been placed on file at the Department of Earth Resources, Colorado State University, Fort Collins, Colorado.

Partitioning Sources of Sampling Variance

The purpose of the ANOVA was to test for sampling error due to analytical techniques and procedures used. Replicate samples were taken at each site and those samples were split in half in the laboratory. The null hypothesis was that the mean concentrations of the samples were equal. A significance level of less than or equal to 10 percent ($\alpha \leq 0.10$) was used.

Variation in the parameters due to replication of the sample was found to be insignificant at all treatments. This indicates that the mid-stream, depth integrated grab samples were representative.

Only two parameters, suspended solids ($\alpha = 0.019$) and fecal streptococci (FS) ($\alpha = 0.03$) showed significant variation in the split sample analysis. Suspended solids concentrations were quite low at Treatments I, II, and III, with only a moderate increase at Treatment IV. The differences may stem from unequal distribution of the suspended solids in the split sample volumes. Even though the field sample was shaken vigorously prior to the splitting procedure, it was very difficult to sustain a homogenous distribution of the sediment in the sample. The larger sediment particles began to settle toward the bottom of the field sample immediately after shaking. This particle settling may be responsible for most of the variance obtained. The FS differences may be due to the inherent variability of the bacteria themselves, including their distribution patterns. Because the distribution varies throughout the sample, differences in counts may be observed. However, the method used is the best available at this time.

In general, very little of the variation in the parameters could be attributed to sampling technique and laboratory methods. When significant differences were present, they were attributable to varying concentrations within the sample itself.

Diurnal Sampling

Diurnal sampling was done to determine whether or not composite samples would be required during routine weekly collection. Table 1 lists the 95 percent confidence intervals that were determined for each parameter. These intervals were constructed to specify how much diurnal fluctuation might be expected. Upon inspection of the intervals, it is apparent that no excessive fluctuations were present for any of the parameters except the indicator bacteria. These fluctuations may be related to the varying amount of fecal contamination present in the streams at a given time, which in turn governs the density of the bacteria. In addition, temperature of the water becomes important, since survival rates of these bacteria are dependent, in part, upon temperature changes. Because morning and evening maximum counts were observed in previous studies, routine sampling was done during the morning hours throughout the study period.

In addition to the confidence intervals, standard error of the estimates was determined to examine the variation. Small standard errors are indicative of small variances. No standard error values greater than 14 were recorded for any of the parameters at Treatments I, II, and III, which indicates minor diurnal fluctuation. At Treatment IV, the only standard error values greater than 14 were for FS counts (74 at the upstream site and 47 at the downstream site). Although these values are not exceedingly high, they did indicate

Table 1. Ninety-five percent (95%) confidence intervals for diurnal sampling.

Parameter	I		II		III		IV	
	U ¹	D ²	U	D	U	D	U	D
SS (mg/l)	1.8-3.5	1.7-4.1	1.7-4.1	2.4-5.1	2.2-4.1	2.2-3.8	12.0-13.2	12.0-13.1
NO ₃ -N (mg/l)	6.9-9.1	6.1-8.2	6.1-8.2	5.9-7.9	3.8-5.8	4.6-5.7	6.6-7.9	7.9-9.6
PO ₄ (mg/l)	.135-.692	.200-.450	.200-.450	.169-.379	.284-.466	.237-.460	.355-.527	.323-.741
Cl (mg/l)	5.1-5.7	5.4-6.3	5.4-6.3	5.2-6.1	4.4-4.7	4.2-4.7	4.3-4.8	4.4-4.8
FC (col/100 ml)	20-45	27-47	27-47	21-93	-0.3-14	21-38	88-149	118-217
FS (col/100 ml)	39-138	44-157	44-157	54-79	18-32	57-87	140-480	224-440

¹U denotes the upstream sampling site for a given treatment.

²D denotes the downstream sampling site for a given treatment.

some diurnal fluctuation. However, part of the fluctuation may have been caused by grazing and the presence of beaver, both of which occurred upstream from the study reach.

In summary, there were no large differences or variations found over a 24 hour period for any of the parameters at any of the four treatments. Therefore, it was concluded that composite sampling was not required and that, similar with other studies such as Kunkle and Meiman (1968), there appeared to be very little benefit from taking more than one bottle of water at a given sampling time.

Routine Sampling

Routine sampling was done to quantify impacts of mountain home developments on stream water quality on a weekly basis. The first year, 1977, had a drier than normal winter, with 914.4 mm of precipitation recorded by a National Oceanic and Atmospheric Association (NOAA) weather station near Allenspark, Colorado. This value was the total for October 1976 through March 1977, and was 1016 mm below the average of 1930.4 mm, normally recorded there during that time. For the following winter, October 1977 through March 1978, 1828.8 mm were recorded, an increase of 914.4 mm. As a result, spring snowmelt runoff was considerably greater at each treatment the second year. Baseflow levels were also higher in 1978 compared to 1977. Consequently, a comparison between the two

sampling seasons with respect to stream discharge will be made throughout this discussion.

Data analysis of routine sampling was performed two different ways. The first sought to determine significant differences in parameters within treatments (between the two sites) and the second between treatments (comparing different treatments to each other).

Within Treatment Variation

Significant differences in each parameter between the upstream and downstream sites at each treatment were tested for. A significance level of less than or equal to 10 percent ($\alpha \leq 0.10$) was used. Mean and standard deviation values for the parameters are listed in Tables 2 and 3.

Discharge 1977. As mentioned previously, lower than normal discharges were measured during the first sampling period, with little or no snowmelt runoff observed. This can be seen quite clearly in Figure 2, which illustrates the discharge relationship for Treatment I. This treatment was on a high flow stream. Figure 3 shows nearly the same pattern for Treatment III, which was on a low flow stream. Discharge relationships for Treatments II and IV display the same patterns as described above, and are located in Appendix A.

Discharge 1978. Discharge increased an average of two to five times at the high flow treatments (I and II) and three to four times at the low flow treatments (III and IV). As shown in Figures 2 and 3,

Table 2. Mean and standard deviation values - 1977.

Parameter	Treatment							
	I		II		III		IV	
	U ¹	D ²	U	D	U	D	U	D
Q (cfs)	29.5 (10.7) ³	31.0 (11.3)	31.0 (11.3)	32.2 (12.0)	0.7 (0.5)	1.0 (0.7)	0.4 (0.4)	0.6 (0.5)
SS (mg/l)	3.7 (2.6)	4.3 (2.3)	4.3 (2.3)	4.1 (2.5)	4.8 (4.9)	4.2 (3.2)	10.0 (3.4)	12.2 (5.4)
NO ₃ -N (mg/l)	5.6 (2.3)	5.7 (1.7)	5.7 (1.7)	5.1 (1.7)	6.1 (2.1)	5.7 (1.8)	7.9 (4.5)	8.5 (3.4)
PO ₄ (mg/l)	0.12 (0.07)	0.15 (0.20)	0.15 (0.20)	0.20 (0.26)	0.13 (0.07)	0.18 (0.20)	0.18 (0.10)	0.18 (0.11)
Cl (mg/l)	5.0 (0.7)	4.9 (0.8)	4.9 (0.8)	5.4 (1.6)	4.0 (0.7)	4.3 (0.9)	4.2 (0.6)	4.7 (0.4)
FC (col/100 ml)	26 (28)	27 (29)	27 (29)	26 (26)	8 (15)	14 (14)	125 (125)	188 (233)
FS (col/100 ml)	170 (369)	139 (252)	139 (252)	122 (191)	21 (31)	29 (24)	129 (173)	185 (214)

¹U denotes the upstream sampling site for a given treatment.

²D denotes the downstream sampling site for a given treatment.

³Standard deviations are the values within the parentheses.

Table 3. Mean and standard deviation values - 1978.

Parameter	Treatment							
	I		II		III		IV	
	U ¹	D ²	U	D	U	D	U	D
Q (cfs)	124.0 (48.7) ³	127.7 (49.7)	127.7 (49.7)	131.5 (50.7)	2.8 (2.4)	3.0 (2.4)	1.4 (1.4)	1.9 (2.0)
SS (mg/l)	5.3 (0.6)	5.4 (0.9)	5.4 (0.9)	5.8 (0.8)	6.9 (1.0)	7.2 (1.1)	15.2 (2.7)	16.4 (3.0)
NO ₃ -N (mg/l)	5.8 (2.5)	6.1 (2.3)	6.1 (2.3)	6.2 (1.7)	7.1 (1.9)	6.9 (1.3)	9.7 (3.7)	9.4 (2.7)
PO ₄ (mg/l)	0.05 (0.02)	0.07 (0.03)	0.07 (0.03)	0.06 (0.02)	0.07 (0.04)	0.09 (0.04)	0.18 (0.12)	0.18 (0.11)
Cl (mg/l)	4.5 (0.3)	4.5 (0.2)	4.5 (0.2)	4.6 (0.3)	4.2 (0.4)	4.1 (0.5)	4.9 (0.5)	4.9 (0.5)
FC (col/100 ml)	36 (57)	26 (40)	26 (40)	35 (93)	4 (8)	13 (15)	102 (135)	130 (138)
FS (col/100 ml)	472 (590)	632 (821)	632 (821)	531 (580)	107 (99)	182 (196)	826 (1494)	733 (1167)

¹U denotes the upstream sampling site for a given treatment.

²D denotes the downstream sampling site for a given treatment.

³Standard deviations are the values within the parentheses.

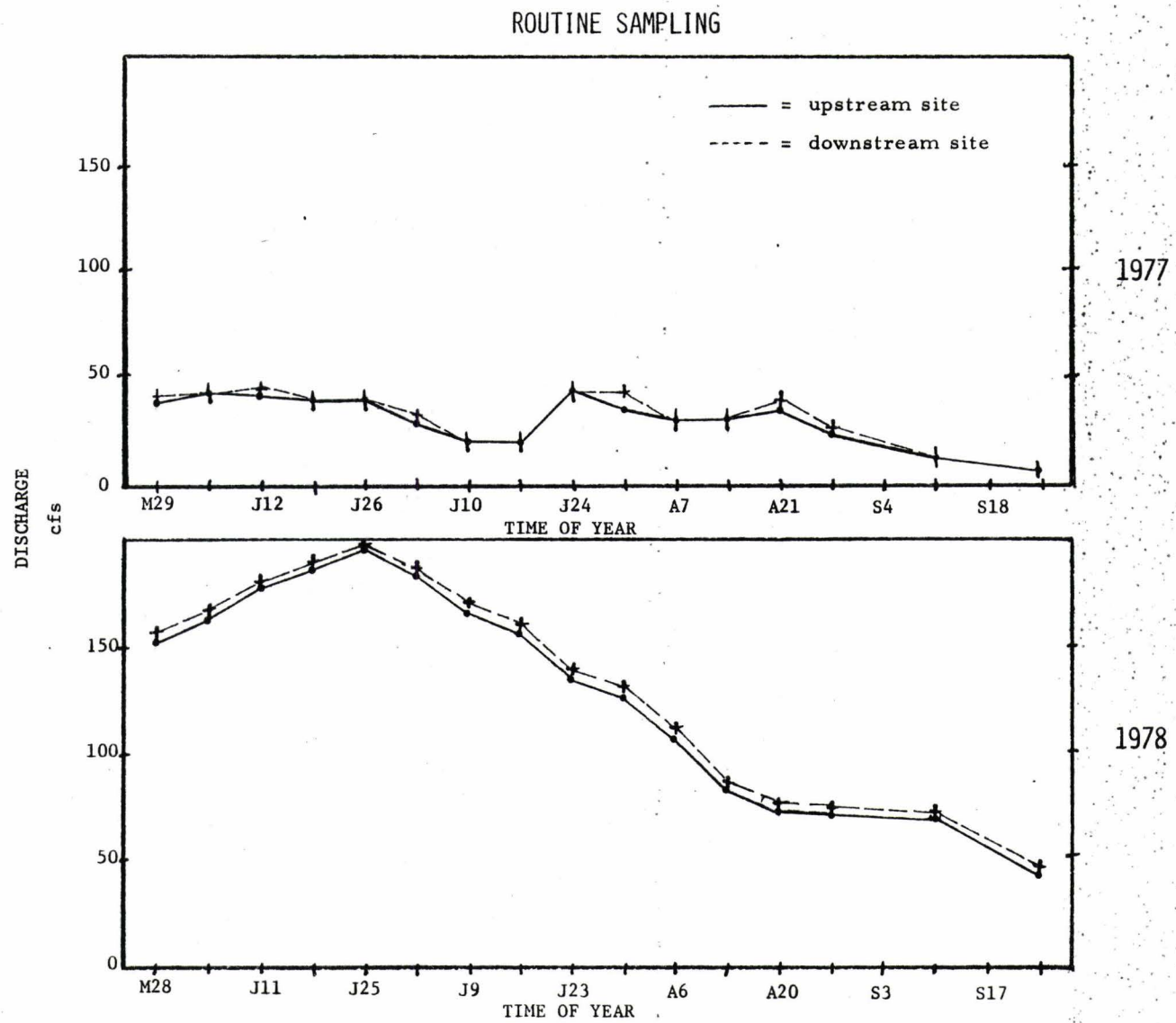


Figure 2. Stream discharge at Treatment I.

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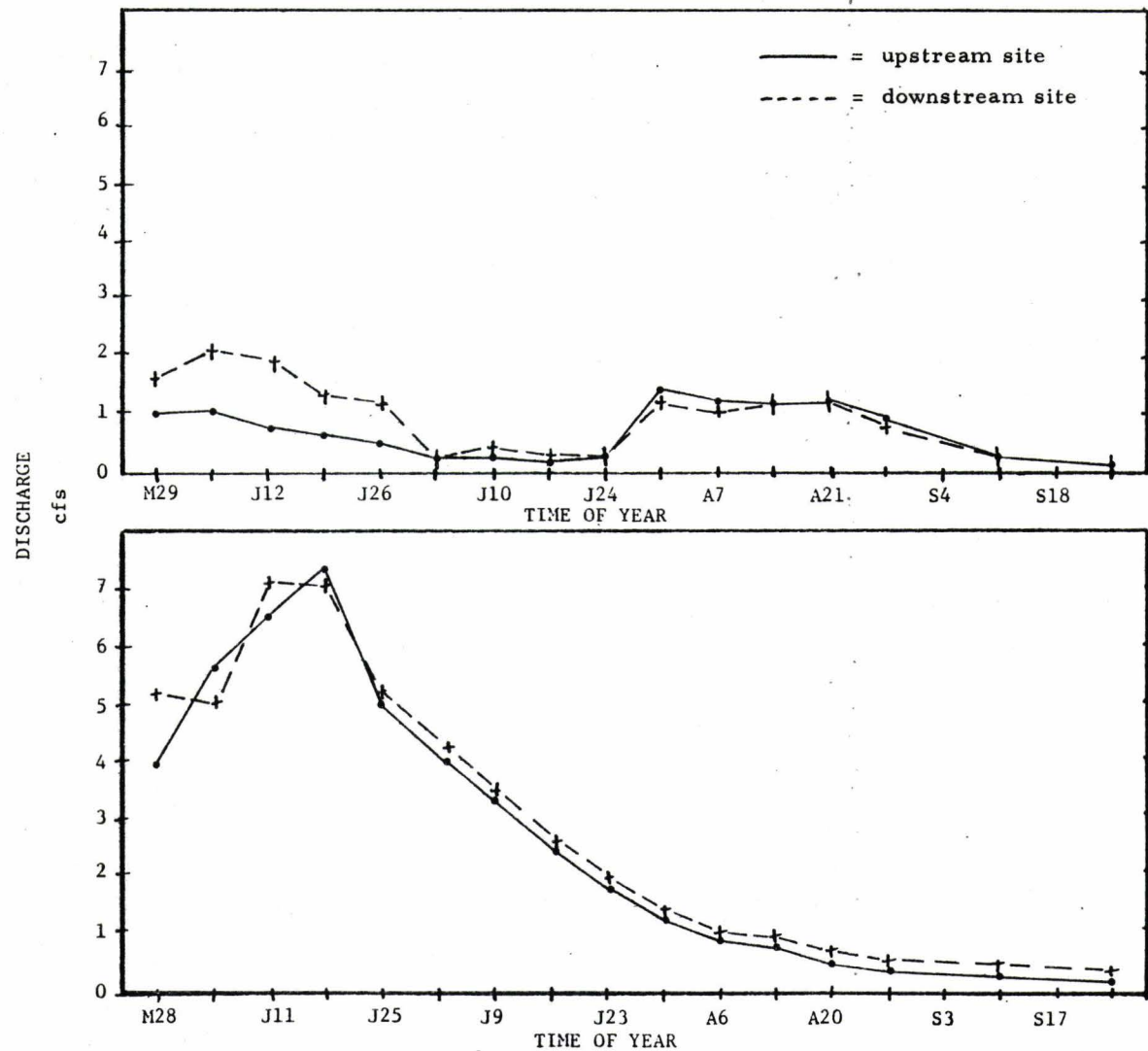


Figure 3. Stream discharge at Treatment III.

snowmelt runoff was much more prominent in 1978 than 1977 and was related directly to the increase in precipitation. In addition, base-flow levels were slightly higher at each treatment during this year. The same was true for Treatments II and IV (Appendix B).

Streamflow levels varied very little within treatments, for either year, as each of the discharge figures show. Levels were similar at both the upstream and downstream sites, indicating a small contribution from groundwater supplies.

Suspended Solids Concentrations 1977. Treatment I had a significant difference in suspended solids concentrations between the two sites at an alpha level of 0.051. However, the concentrations only varied from one to three mg/l and had small standard deviations (Table 2). In addition, concentrations were sometimes greater at the upstream site (Figure 4), indicating that the differences may have been channel derived.

There were no significant differences found at Treatments II and III. Their suspended solids relationships are found in Appendices C and D.

Significant differences ($\alpha = 0.07$) were found between the two sites at Treatment IV. Concentrations were consistently higher at the downstream site (Figure 5). The variation between sites could be attributed to the new road and home construction that was done very near the stream.

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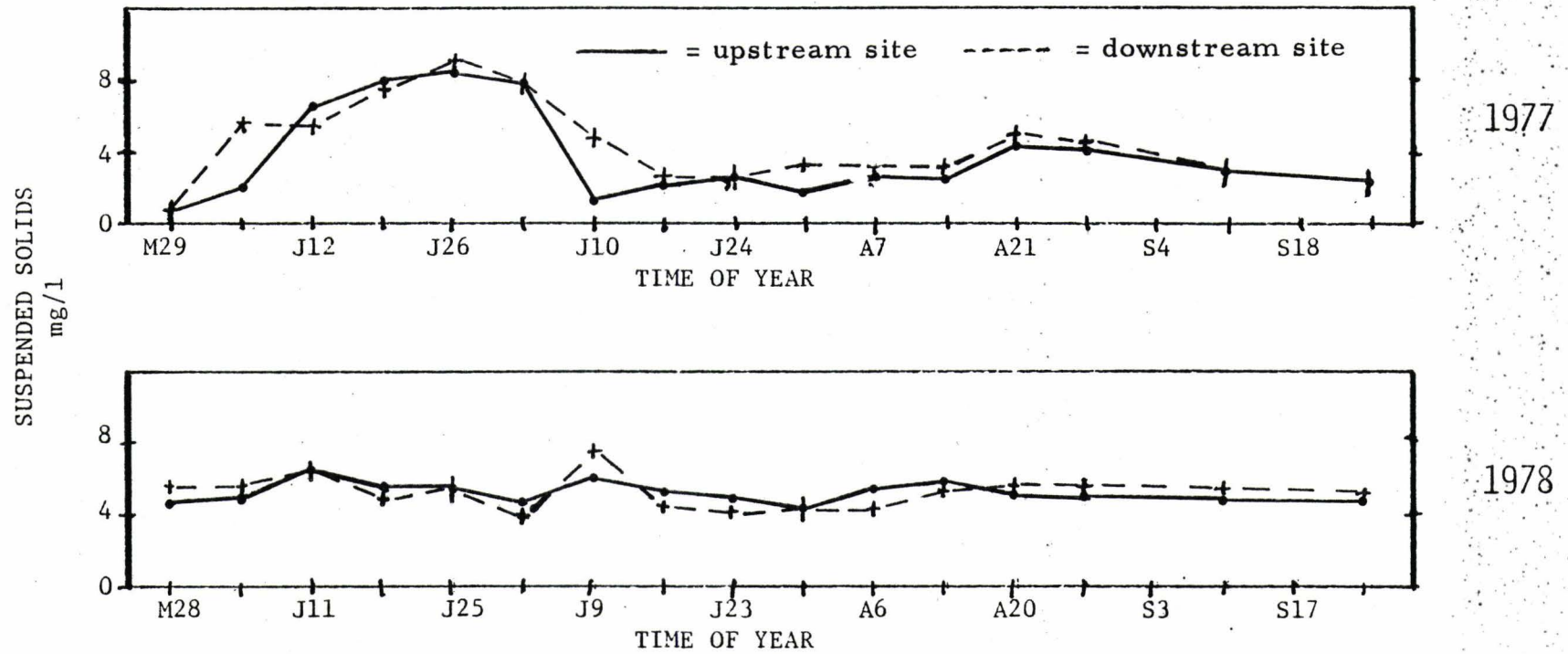


Figure 4. Suspended solids concentrations at Treatment I.

Suspended Solids Concentrations 1978. No significant differences were found between sites at Treatments I, II, and III. However, concentrations increased an average of 1-3 mg/l at Treatments I and II and 2-3 mg/l at Treatment III. These increases were due to the increased streamflow since the concentrations were similar at both the upstream and downstream sites.

A significant difference ($\alpha = 0.011$) between sites was found at Treatment IV. Again, as shown in Figure 5, concentrations were nearly always higher at the downstream site, with the increases caused by the continuous construction practices occurring in the area. The concentrations were greater than those observed in 1977, due in part to increased streamflow as well as the increased construction.

Nitrate-Nitrogen Concentrations 1977. There were no significant differences found between sites for any of the four treatments. Often times, concentrations were greater at the upstream site, as Figure 6 illustrates. This was also true for the remaining treatments (Appendices E, F and G).

Nitrate-Nitrogen Concentrations 1978. Again, no significant differences were found at any of the treatments and concentrations were higher at the upstream site a number of times (Figure 6 and Appendices E, F and G). Concentrations increased up to two mg/l in 1978 compared to 1977, but the increases were proportional at

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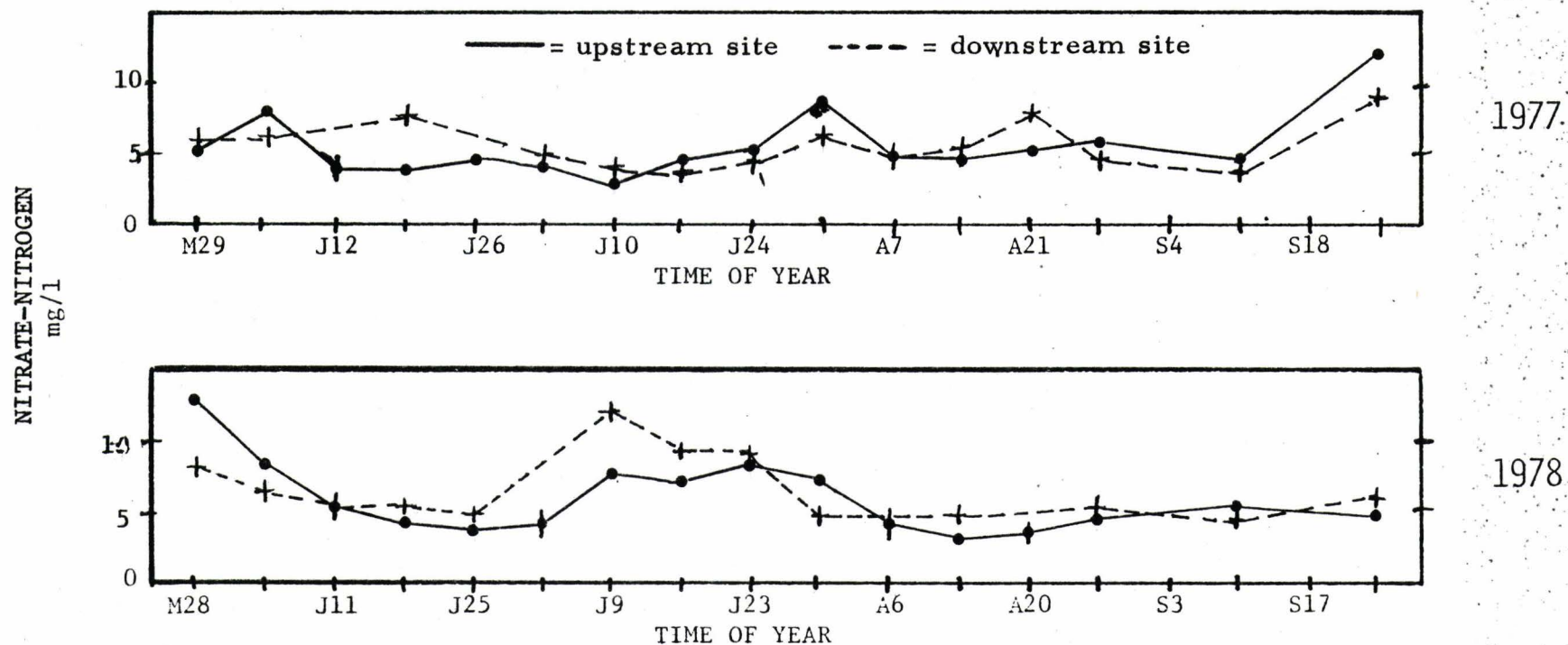


Figure 6. Nitrate-nitrogen concentrations at Treatment I.

both sites for the treatments. Therefore, the increases were not attributable to the developments.

Orthophosphate Concentrations 1977. Significant differences were not found at any of the treatments. Similar to nitrate-nitrogen, orthophosphate concentrations were greater at the upstream sites almost as often as they were at the downstream sites (Figure 7). This points to minor man-caused degradation of the water quality with respect to orthophosphate. Graphical illustrations of the concentrations are presented in Appendices H and I, also.

Orthophosphate Concentrations 1978. Concentrations were significantly different ($\alpha = 0.01$) between the sites at Treatment I. Figure 7 shows that concentrations were consistently greater at the downstream site. This indicated some influence by the developments, but the impact appeared to be minor since orthophosphate concentrations less than or equal to 0.20 mg/l should not cause undesirable enrichment in the stream (Flack, 1976).

No significant differences were found at Treatments II and IV, but differences between sites at Treatment III were significant at a level of one percent ($\alpha = 0.01$). Concentrations were regularly higher at the downstream site (Figure 8), indicating a negative impact from the development. However, similar to Treatment I, concentrations were never greater than 0.20 mg/l and therefore eutrophication was not a problem.

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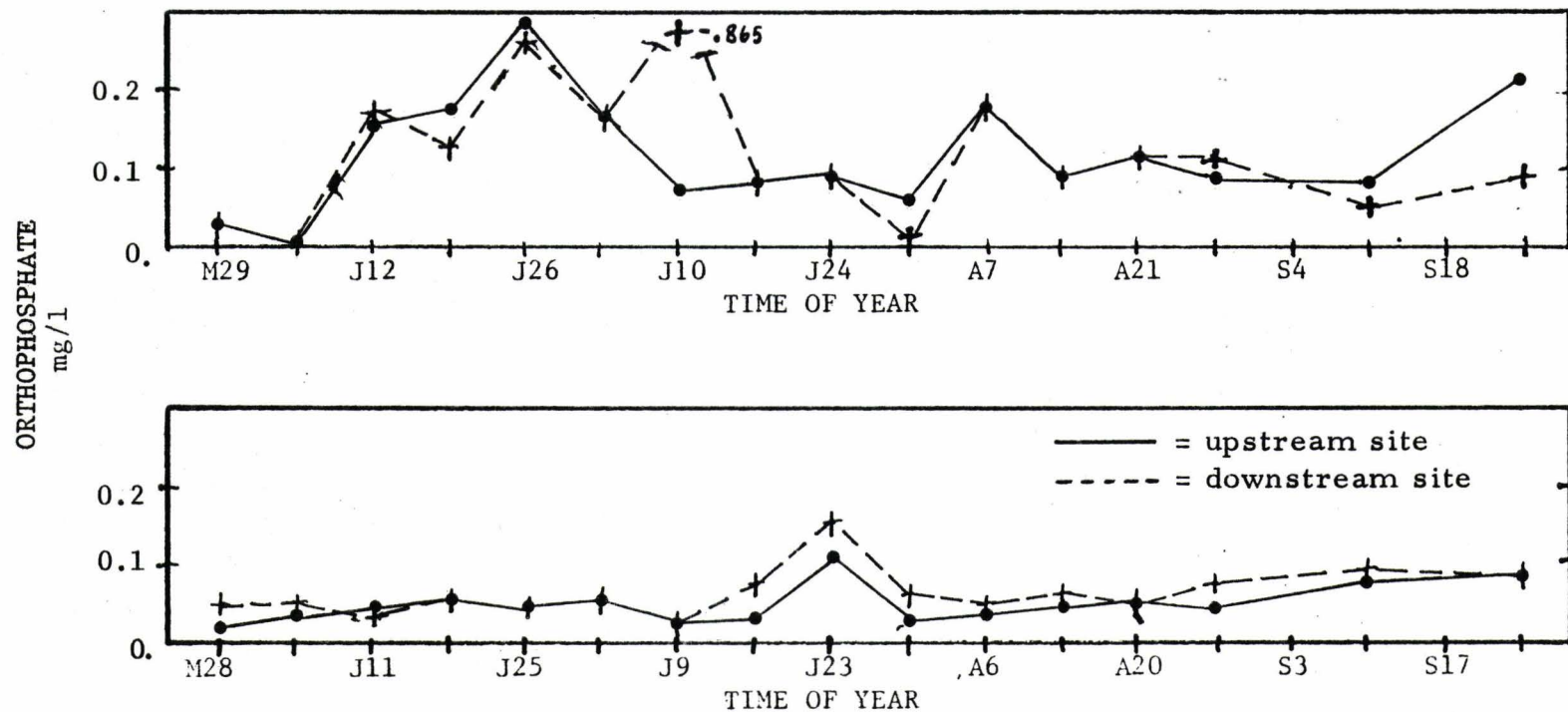


Figure 7. Orthophosphate concentrations at Treatment I.

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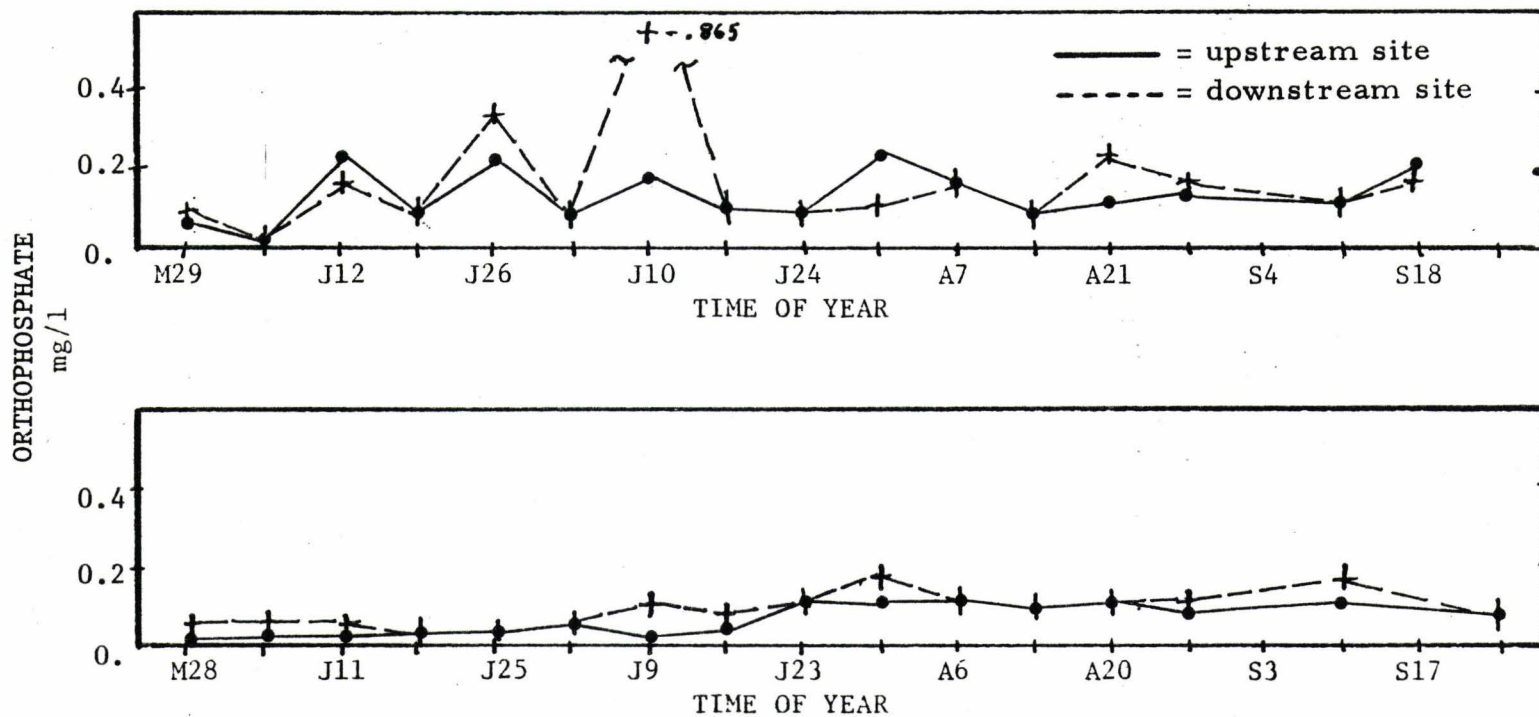


Figure 8. Orthophosphate concentrations at Treatment III.

The orthophosphate concentrations decreased noticeably at all treatments in 1978 compared to 1977, indicating a dilution effect. In all instances, average concentrations were not high enough to cause undesirable stream enrichment.

Chloride Concentrations 1977. No significant differences were found at Treatments I and II, where concentrations were nearly the same at both sites throughout the year (Appendices J and K).

Concentrations were significantly different at Treatments III ($\alpha = 0.06$) and IV ($\alpha = 0.01$). In both instances, concentrations were consistently greater at the downstream site, but only varied 1-2 mg/l (Figures 9 and 10). The fact that the differences were significant infers a negative impact from the development, and more specifically, their sewage systems. But since the differences were only one or two mg/l, the impacts appeared to be minor.

Chloride Concentrations 1978. There were no significant differences observed in concentrations at any treatment for this sampling period. Concentrations remained nearly the same at both the upstream and downstream sites (Figures 9 and 10 and Appendices J and K). This stability suggests little or no degradation caused by the developments during this time.

Chloride concentrations remained the same or decreased slightly in 1978 compared to 1977. The decreases may be related in part to dilution effects. Because chlorides are not diminished to any

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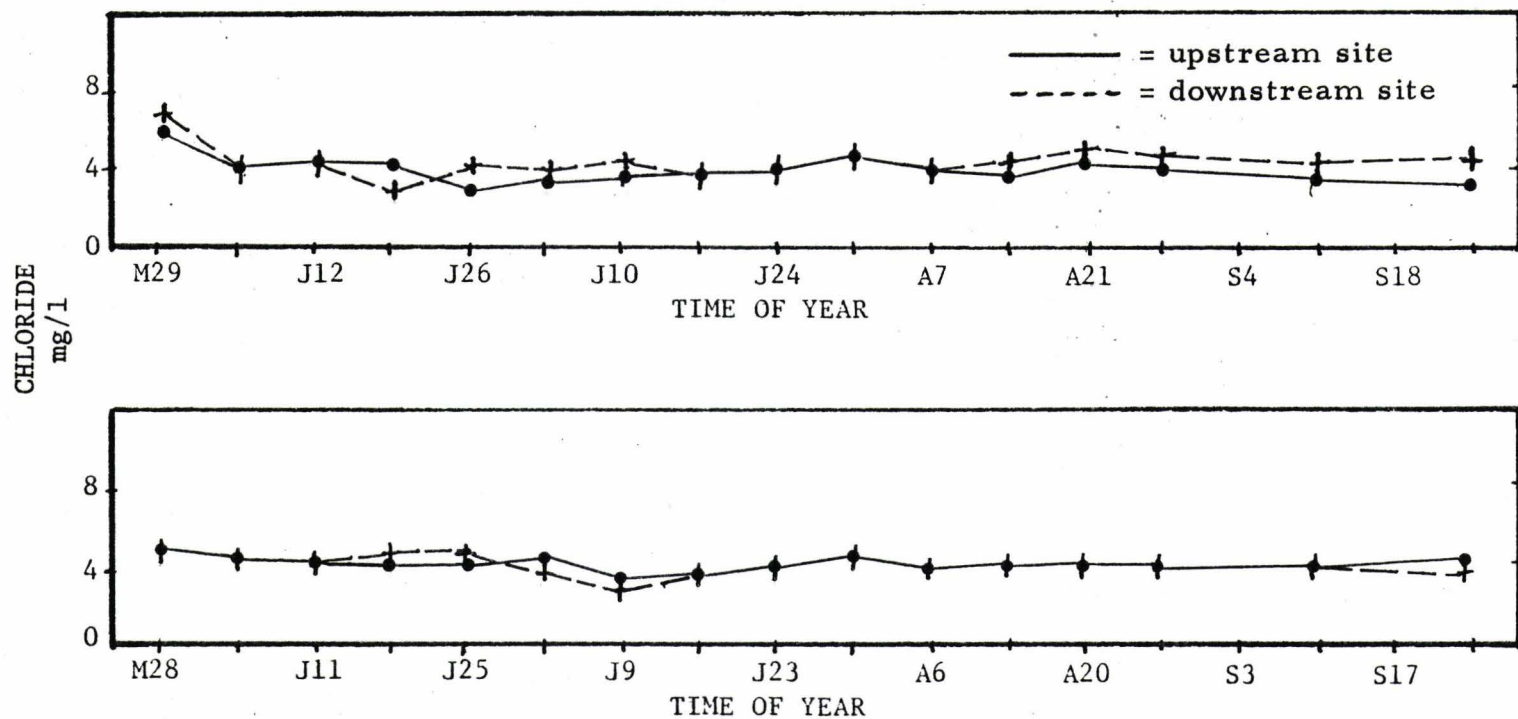


Figure 9. Chloride concentrations at Treatment III.

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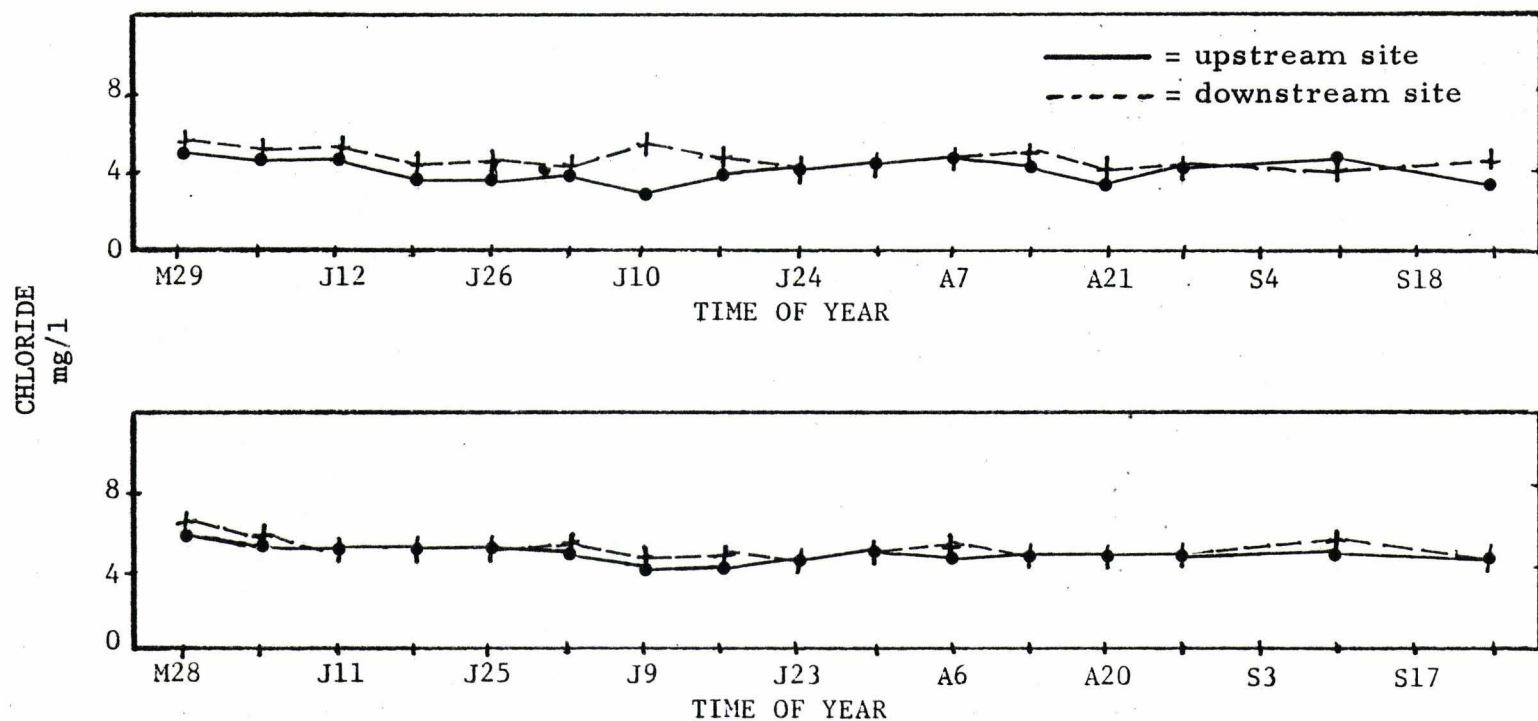


Figure 10. Chloride concentrations at Treatment IV.

great degree in passage through the soil, sewage leaks of even a slight magnitude should be noticeable. Since no such leaks were observed and because concentrations varied only slightly, it may be assumed that the developments were not seriously affecting the water quality with respect to chloride concentrations.

Fecal Coliform Densities 1977. Fecal coliform (FC) counts showed no significant differences at any of the treatments. Density relationships with respect to time of year are shown in Figures 11a, 11b, 12a, 12b and Appendices L and M. These graphs illustrate that the counts were often equal or greater at the upstream site, indicating minor impact of fecal contamination from the developments. In addition, it is readily noticeable that the bacteria densities varied more at the low streamflow treatments (III and IV). Morrison and Fair (1966) report that variation in coliform counts were a function of wetted stream perimeter, dilution and stream velocity. Greater values for these variables produced more uniform counts of FC bacteria.

Fecal Coliform Densities 1978. As in 1977, no significant differences in FC densities were found in 1978. Average counts increased slightly at Treatments I and II compared to 1977 and may be related to the increased streamflow. Many studies, including those by Geldreich (1967) and Kunkle (1965), have shown that both channel banks and bottom are capable of storing and releasing

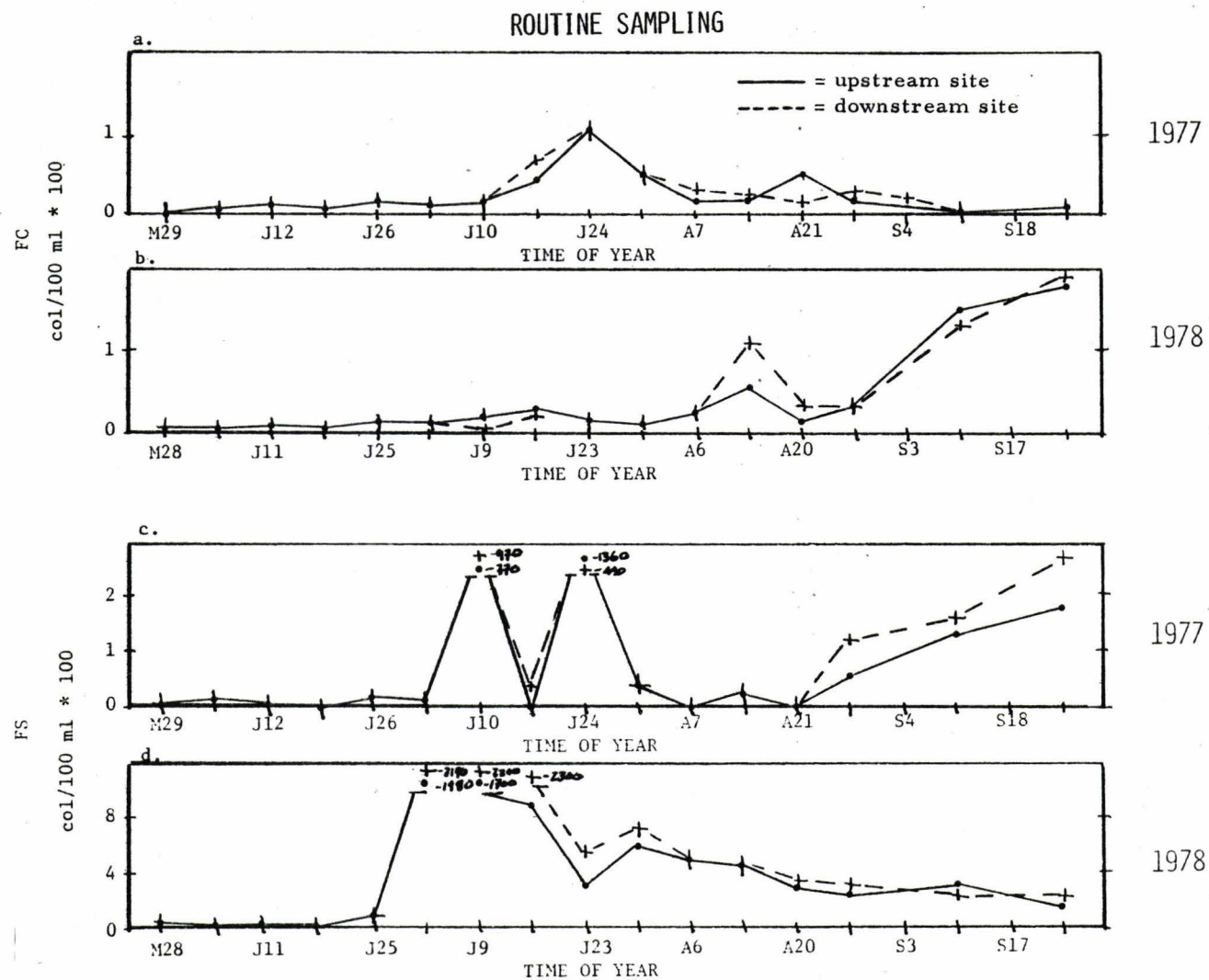


Figure 11. Fecal coliform and fecal streptococci densities at Treatment I.

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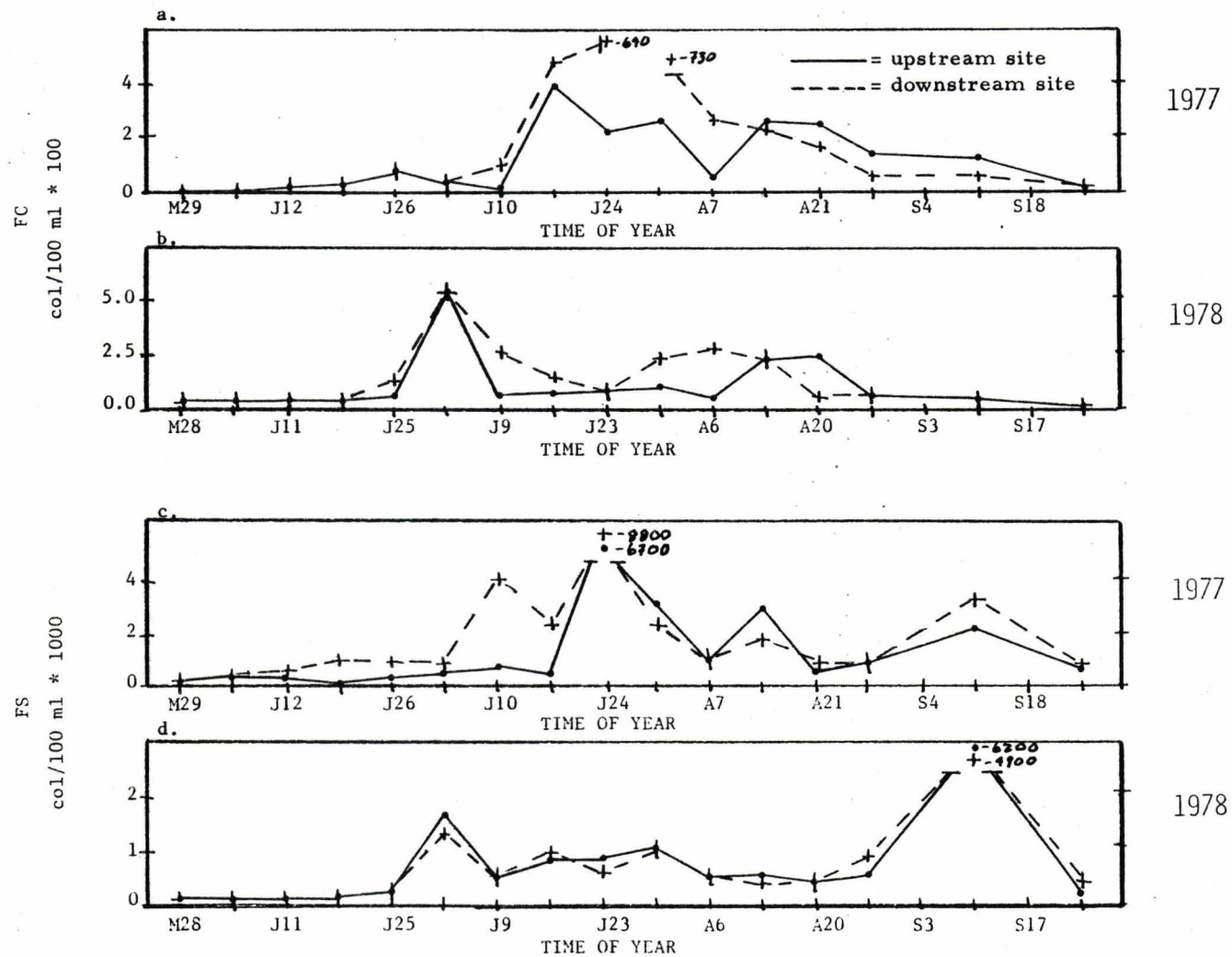


Figure 12. Fecal coliform and fecal streptococci densities at Treatment IV.

bacteria, the storage and release processes being dependent on stream discharge changes. Treatments III and IV had a slight decline in average counts, where the discharge increases were apparently not large enough to raise the counts through "flushing" of the channel banks and bottom.

Fecal Streptococci Densities 1977. Treatments I, II, and III did not show significant differences between sites. Counts were quite similar at both sites throughout the sampling period (Figures 11c and 11d and Appendices L and D). These relationships suggest that only a minor amount of fecal contamination was being contributed by the developments.

A significant difference ($\alpha = 0.06$) in FS densities was found at Treatment IV. Since counts were appreciably higher at the downstream site the majority of time, a negative impact from the development is suggested (Figure 12c).

Fecal Streptococci Densities 1978. FS densities were significantly different at Treatment I ($\alpha = 0.10$). Figure 11d illustrates the relationship between two sites, with counts being consistently greater at the downstream site. Again, influence from the development was indicated.

The remaining treatments showed insignificant differences in counts. Densities were similar at both sites in most instances, suggesting only a minimal amount of increased fecal contamination between sites.

FS counts increased noticeably at all treatments in 1978 compared to 1977. These increases may also be attributable to increased streamflow and subsequent banks and bottom "flushing."

FC/FS Bacteriological Ratios. Geldreich (1967) writes that although the FC test will not distinguish between the contamination of human versus nonhuman warm-blooded animal wastes, such a separation can be established through density relationships of FC to FS on the same sample effluents or receiving waters. Geldreich and Kenner (1969) conclude that parallel examination for FC densities would confirm the validity of the FS densities and be useful in the development of the ratio relationship between these two bacterial indicator systems.

FC to FS ratios were determined for both sites of each treatment for both years, and are listed in Table 4.

Table 4. FC/FS ratios - routine sampling.

Year	Treatment							
	I		II		III		IV	
1977	U ¹	0.15	U	0.19	U	0.36	U	0.97
	D ²	0.19	D	0.21	D	0.46	D	1.02
1978	U	0.08	U	0.04	U	0.04	U	0.12
	D	0.04	D	0.07	D	0.07	D	0.18

¹U denotes the upstream sampling site for a given treatment.

²D denotes the downstream sampling site for a given treatment.

FC/FS ratios less than 0.7 are strong evidence that the source of contamination is from livestock and wildlife wastes. Ratios greater than 4.0 strongly suggest the contamination is derived from human wastes.

Using the ratios calculated for 1977 and the criteria given above, it could be assumed that the source of the contamination present at the four treatments was predominantly livestock and wildlife, both of which were observed in the areas. There were no ratios greater than 4.0. The majority of the ratios were less than 0.7, and those that were greater than 0.7 were only slightly so (Treatment IV). The fact that the FS densities were significantly different at Treatment IV now takes on less importance.

The same was true for 1978, as all ratios were less than 0.7. In each instance, the ratios decreased noticeably, since FC counts did not increase proportionally compared to the increase in FS counts.

It was assumed from these ratios that the developments along the streams studied, and more specifically the type of sewage facilities utilized, had only a minor impact on the water quality with respect to fecal contamination.

Between Treatment Variation

A two-way analysis of variance comparing site versus date was used to test for significant differences in parameters between certain

treatments. A significant level of less than or equal to 10 percent ($\alpha \leq 0.10$) was used.

Four comparisons were made. The first compared Treatment I to Treatment II to test for differences due to housing density on a high flow (80 cfs) stream. Treatment I had high (52 houses/km) and Treatment II moderate housing density (34 houses/km). Both treatments utilized septic tanks for sewage disposal.

The second comparison was between Treatments I and III to test for differences due to varying streamflow. Treatment I was on a high flow (80 cfs) stream and Treatment III was on a low flow (1-2 cfs) stream. Both had high housing densities with septic tanks.

The next comparison sought to identify any variation due to different housing densities on a low flow stream. Treatments III and IV were compared, with III having a high density (55 homes/km) and IV a moderate density (32 homes/km).

The fourth comparison examined differences due to type of sewage facilities utilized. Treatments I, II, and III, all with septic tanks, were compared to Treatment IV, which used a sewage line leading to a secondary treatment plant.

For 1977, there were no significant differences in any of the parameters for any of the comparisons. This suggested that the additional homes did not adversely affect the water quality at these treatments, regardless of streamflow conditions or sewage facilities used.

In 1978, the only significant differences were found for suspended solids and orthophosphate concentrations when comparing either Treatment III separately, or Treatments I, II, and III combined, to Treatment IV. In every instance, the differences were due primarily to the road and home construction at Treatment IV. Suspended solids concentrations were noticeably higher at Treatment IV than at any of the other treatments. Associated with increased sediment loads often times is increased phosphate concentrations. Sediment is one of the major mechanisms of transport for phosphates from their source to the stream. Therefore, it may be assumed that these differences were not due to different housing densities, streamflows or sewage facilities, but rather to construction practices that resulted in increased sediment loads in the stream. The fact that discharge increased significantly in 1978 compared to 1977 seemed to have no effect on any of the comparisons.

Storm Sampling

Storm sampling was done to test for impacts the developments might have on the water quality of the streams during stormflow. Because the storm events were so sporadic and unpredictable, and because of the relatively long traveling time and distance from Fort Collins to the study area, sampling was severely limited.

Frontal Storm at Treatments I and II

A six-hour frontal storm was monitored at Treatments I and II on 3 August 1978. Figures 13 and 14 show an increase in discharge of about five or six cfs at both sites for both treatments. Associated with this increase in discharge were increases in suspended solids concentrations and FC and FS densities. However, as Figures 15 and 16 illustrate, concentrations were quite similar at both the upstream and downstream sites. Often times, they were greater at the upstream site. This suggests that the developments were not significantly affecting the water quality during stormflow and that the variances present are probably channel derived.

Table 5 compares the means of the parameters obtained in storm sampling to those observed during routine sampling. The values for the storms were higher at each site for both treatments. This implies that the increase in suspended solids may have been derived from the stream's banks and bottom, as well as the increases in bacteria. As stated previously, substantial numbers of bacteria have been observed to be released from stream banks and bottom during substantial increases in discharge.

Convective Storms at Treatment III

Two convective storms were sampled at Treatment III, one on 29 July 1978 (30 minutes duration) and the other on 25 August 1978 (20 minute duration). Figure 17 shows the discharge relationship

STORM SAMPLING

8/3/78

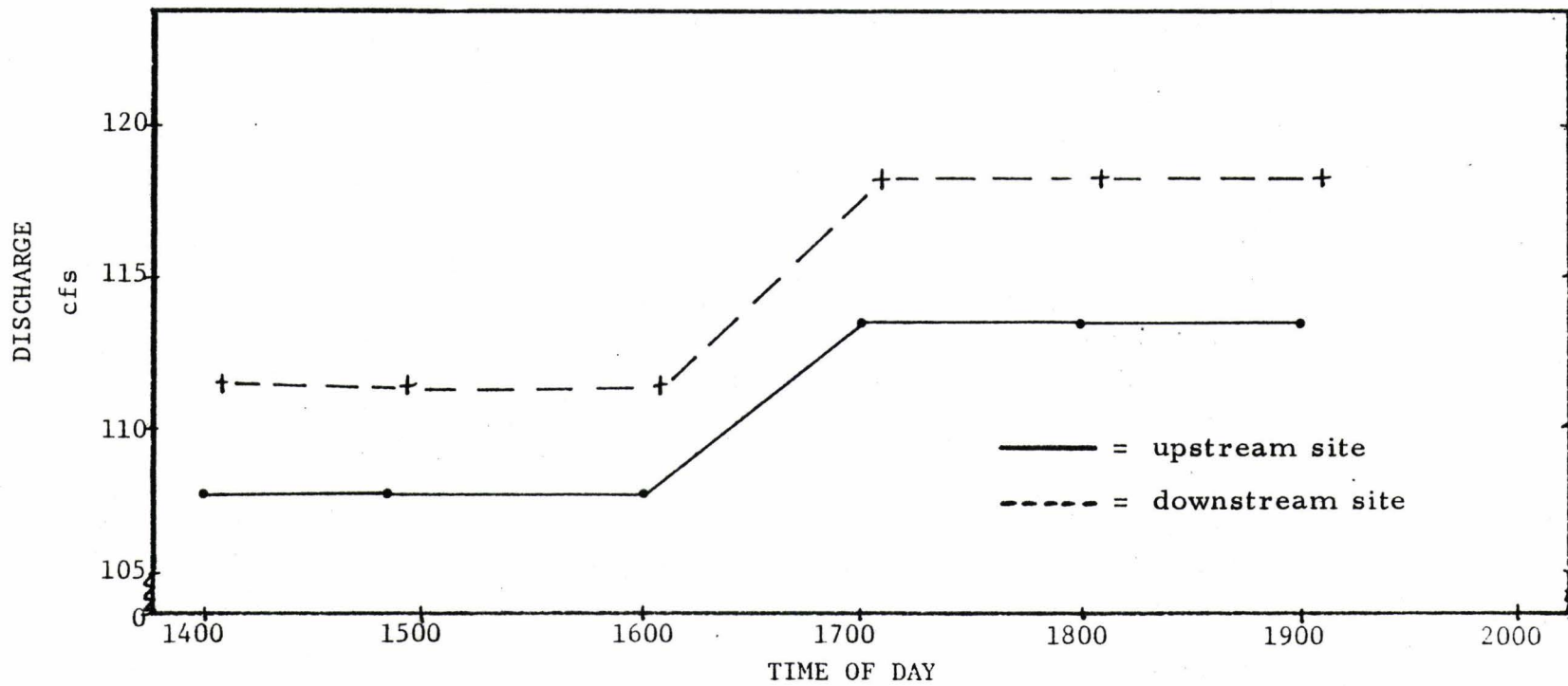


Figure 13. Storm discharge at Treatment I.

STORM SAMPLING
8/3/78

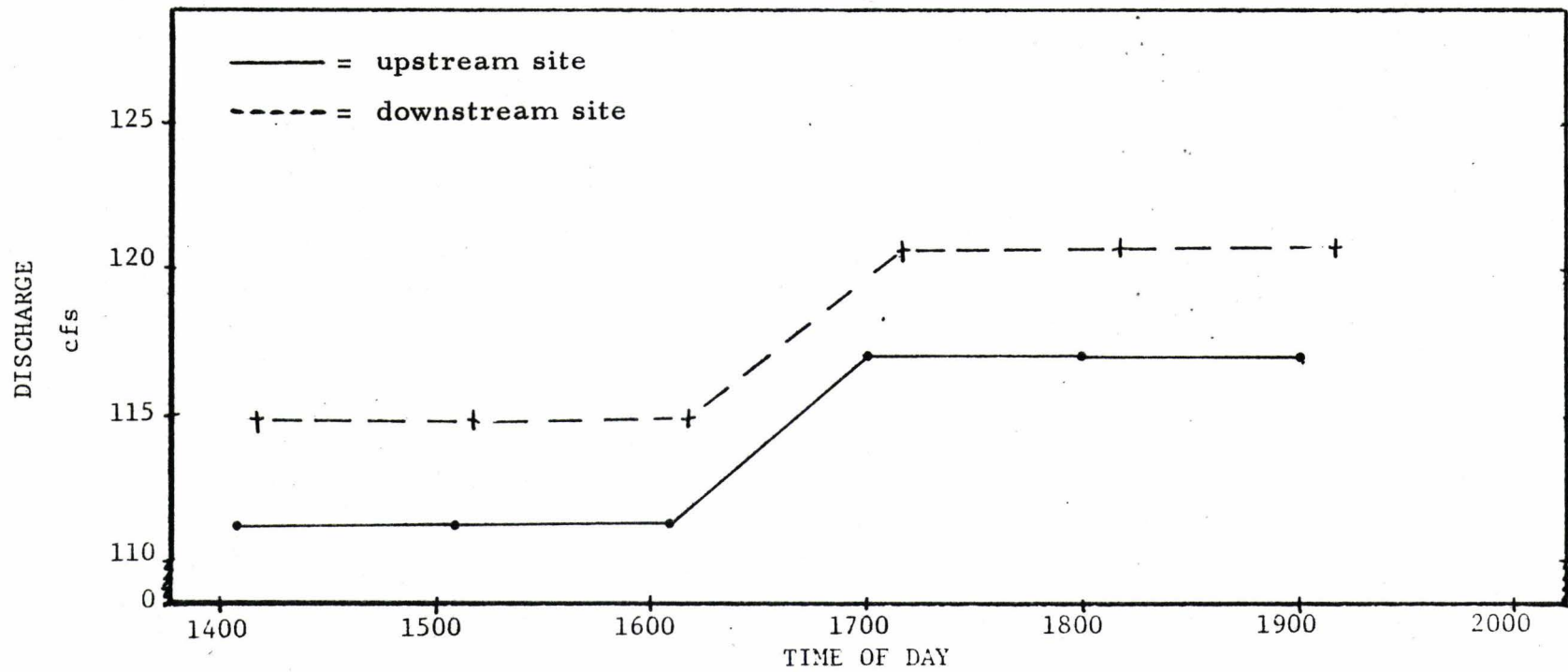


Figure 14. Storm discharge at Treatment II.

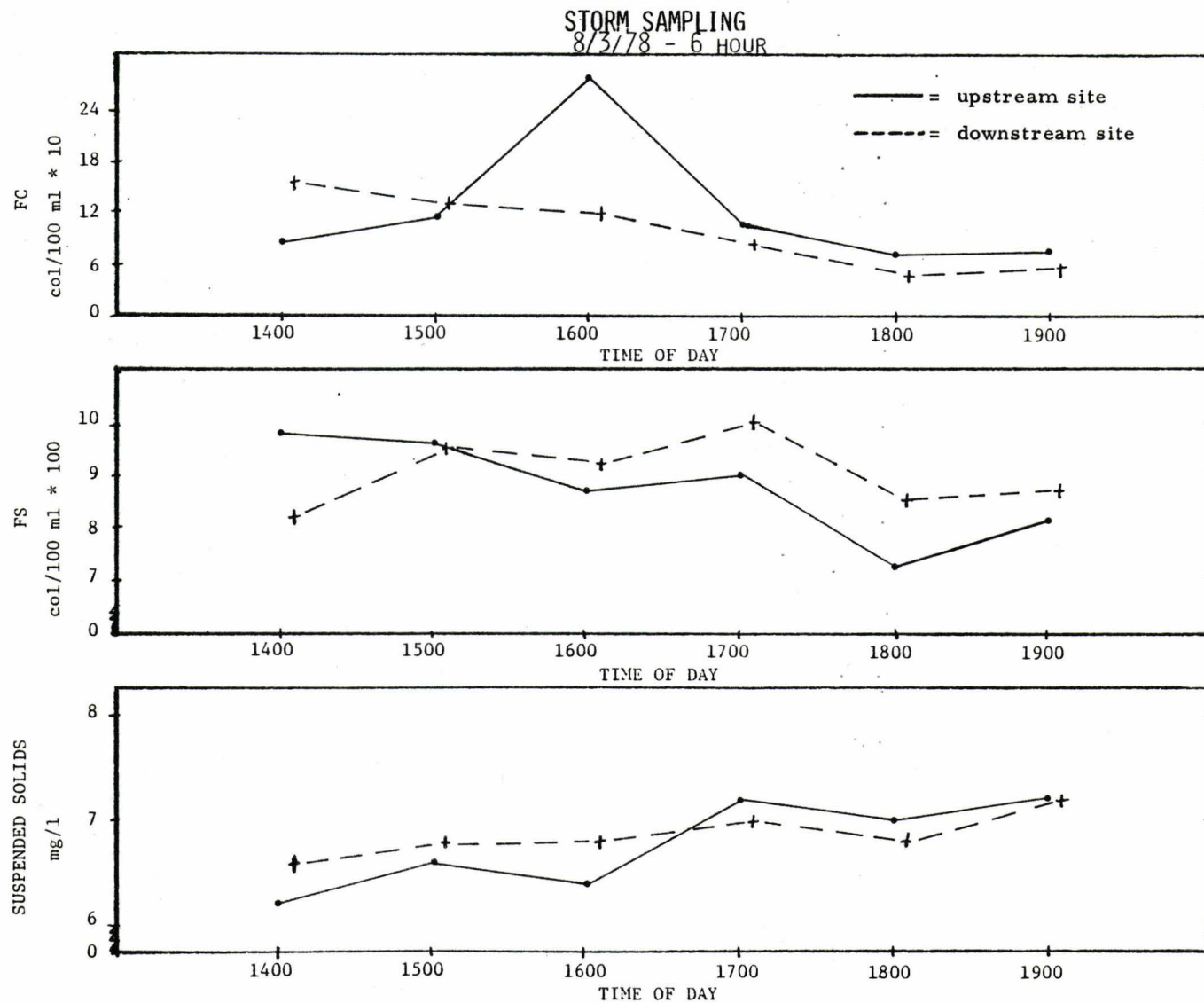


Figure 15. Storm concentrations of FC, FS and SS at Treatment I.

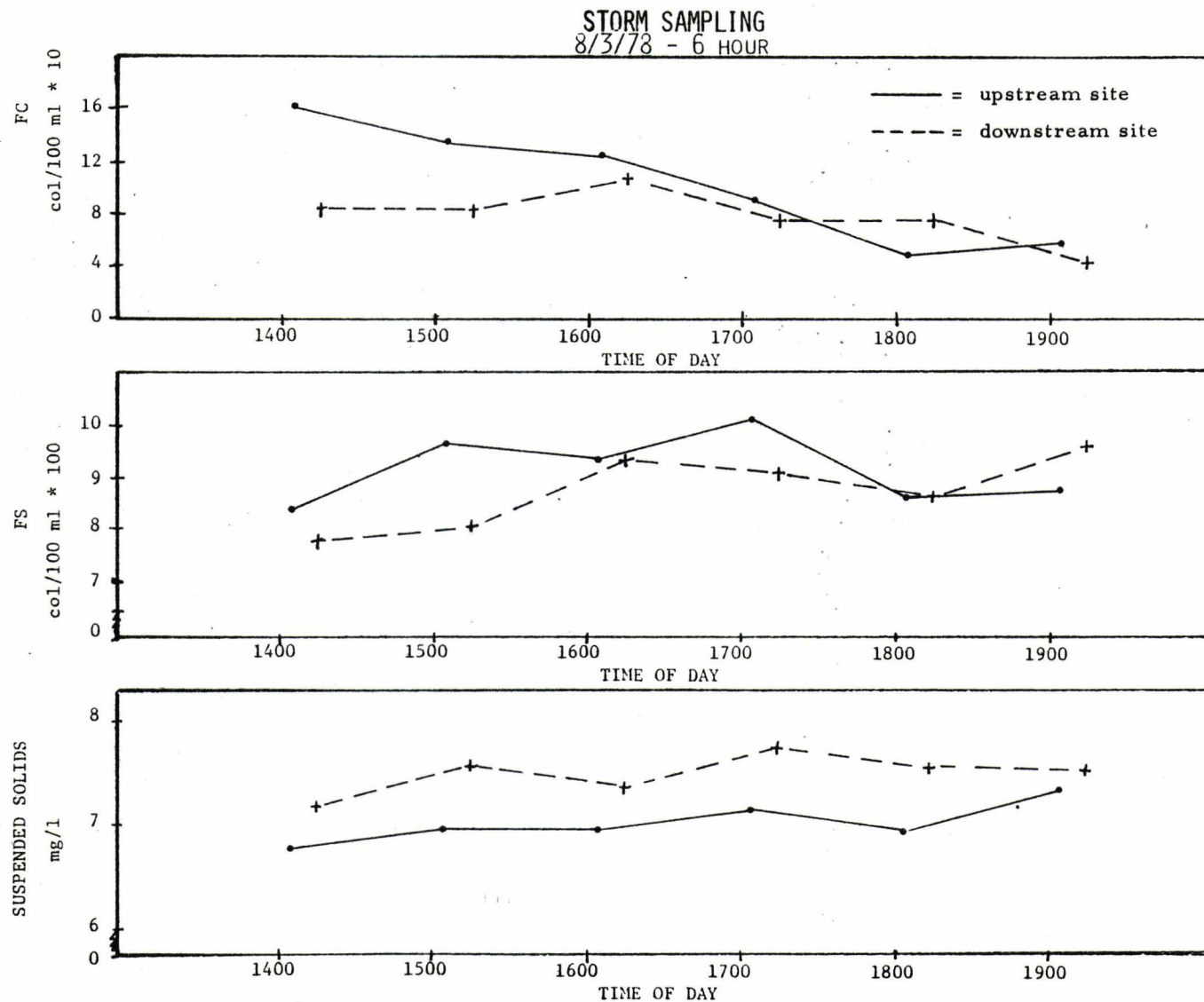


Figure 16. Storm concentrations of FC, FS and SS at Treatment II.

Table 5. Mean comparison - routine versus storm sampling.

Treat- ment		Routine Sampling						Storm Sampling					
		1977			1978			I			II		
		SS ¹	FC ²	FS ²	SS	FC	FS	SS	FC	FS	SS	FC	FS
I	U ³	3.7	26	170	5.3	36	472	6.8	126	873	--	--	--
	D ⁴	4.3	27	139	5.4	26	632	6.9	103	902	--	--	--
II	U	4.3	27	139	5.4	26	632	6.9	103	902	--	--	--
	D	4.1	26	122	5.8	35	531	7.3	77	863	--	--	--
III	U	4.8	8	21	6.9	4	107	8.1	79	2433	7.1	28	910
	D	4.2	14	29	7.2	13	182	8.3	132	2500	7.4	32	1193
IV	U	10.0	125	129	15.2	102	826	18.3	346	5720	16.7	178	7160
	D	12.2	188	185	16.4	130	733	19.6	240	5980	18.1	252	7240

¹Unit is mg/l.

²Unit is col/100 ml.

³U denotes the upstream sampling site for a given treatment.

⁴D denotes the downstream sampling site for a given treatment.

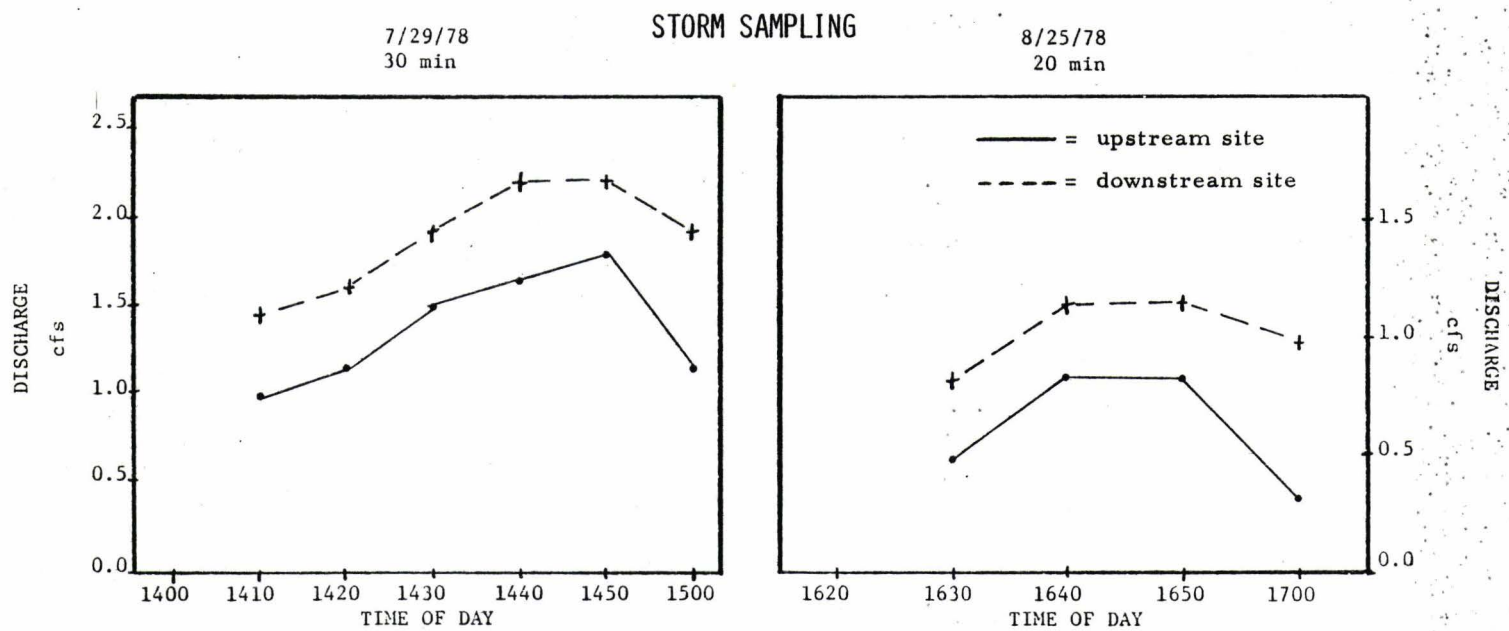


Figure 17. Storm discharge at Treatment III.

obtained for the two storms. Streamflow increased about 1.5 cfs for the first event and 0.5 cfs for the second. The increase in suspended solids concentrations are illustrated in Figure 18. The similarity between the upstream and downstream sites is evident in both cases. Although the bacteria were a bit more variable, they too were quite similar at both sites (Figure 19). As Table 5 shows, both the FC and FS counts increased appreciably compared to routine sampling values. But they increased at nearly the same rate at both the upstream and downstream sites, pointing to minor man-caused contamination from the development.

Convective Storms at Treatment IV

Two storms of a convective nature were sampled at Treatment IV, the first on 29 July 1978 (20 minute duration) and the second on 26 August 1978 (25 minute duration). Figure 20 illustrates the increases in streamflow observed for both storms. Discharge increased about 0.5 cfs for the first event and 0.1 cfs for the second. Suspended solids concentrations increased noticeably, with higher values consistently recorded at the downstream site (Figure 21). The increases between sites were attributable to construction in the area, especially the new roads. Both the FC and FS densities increased appreciably, as illustrated in Figure 22. Table 5 shows the average counts that were recorded. Increases were similar at both sites which again suggests a minor impact from the development. The

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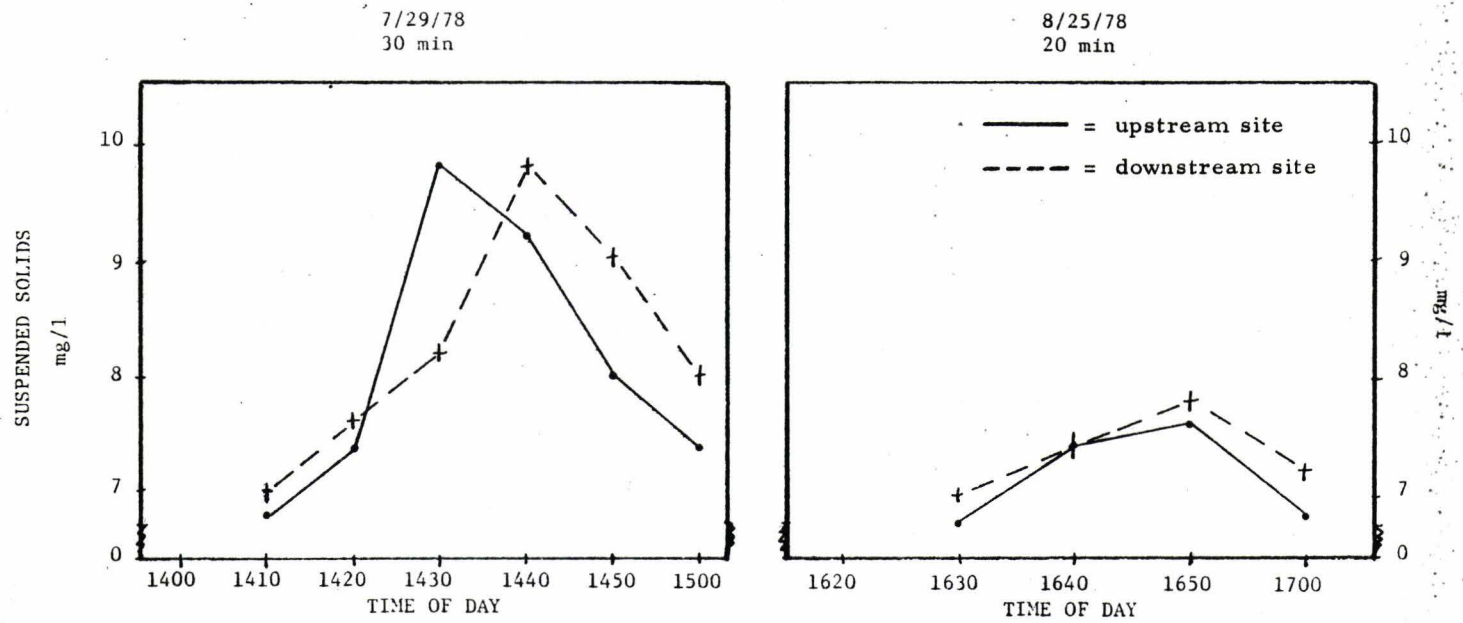


Figure 18. Storm concentrations of SS at Treatment III.

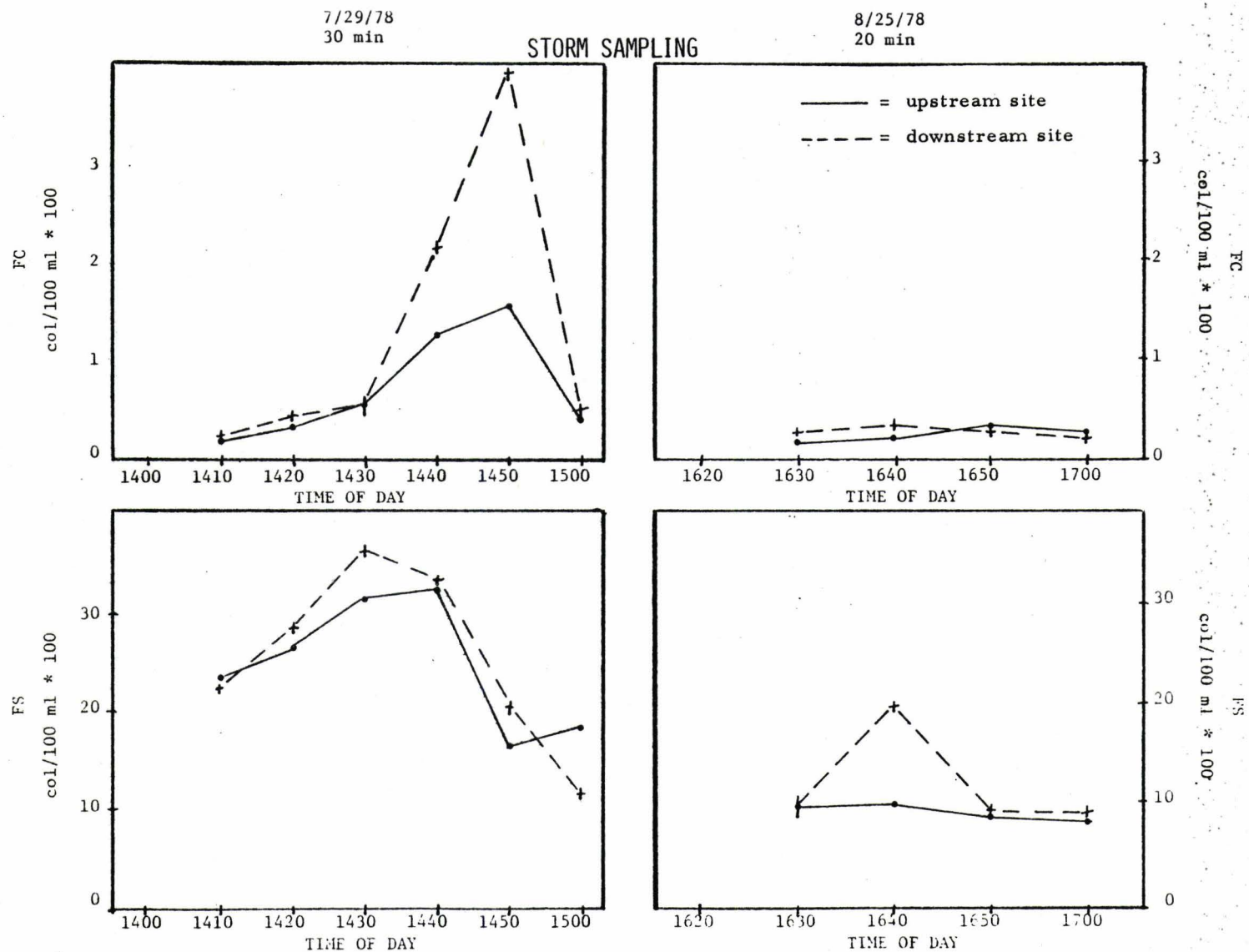


Figure 19. Storm concentrations of FC and FS at Treatment IV.

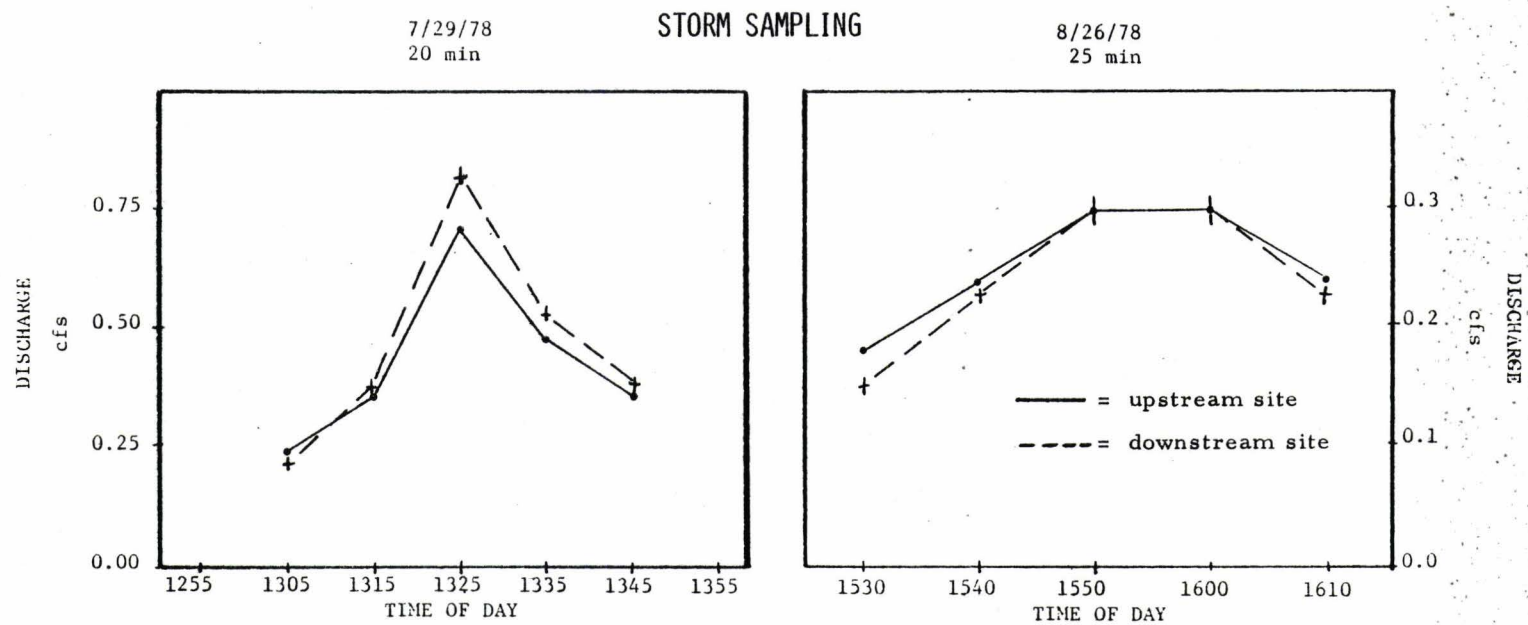


Figure 20. Storm discharge at Treatment IV.

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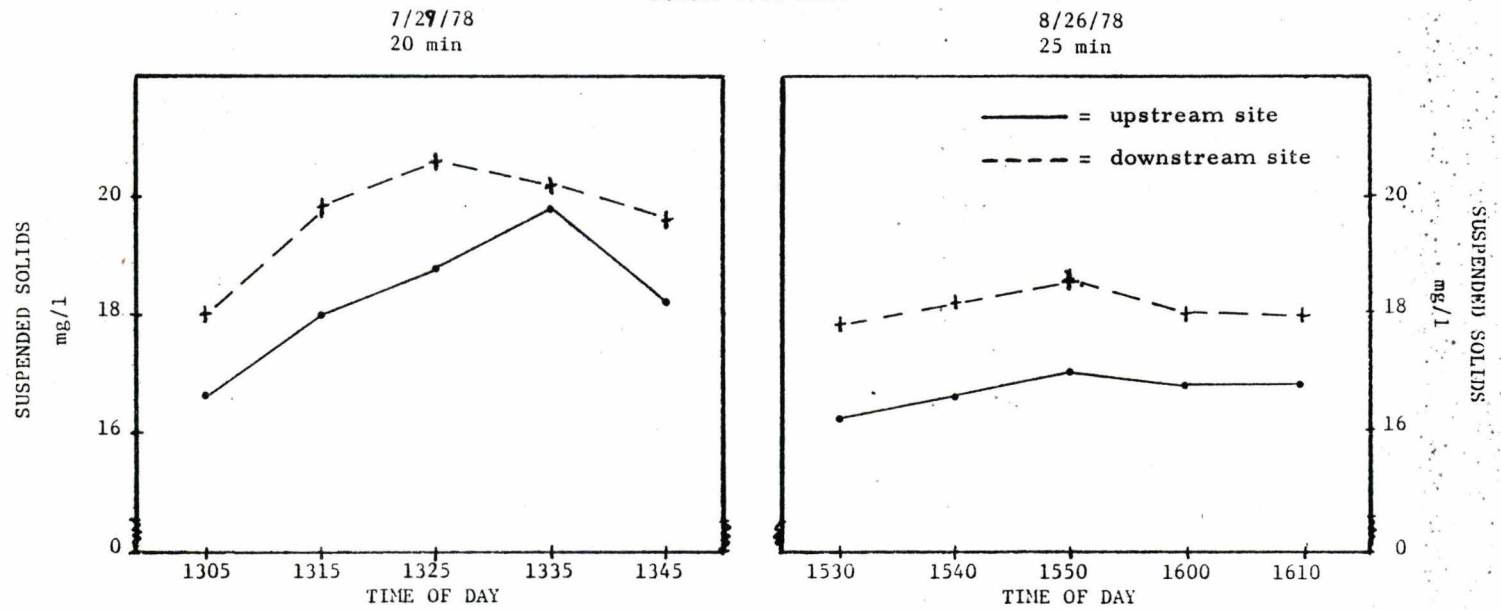


Figure 21. Storm concentrations of SS at Treatment IV.

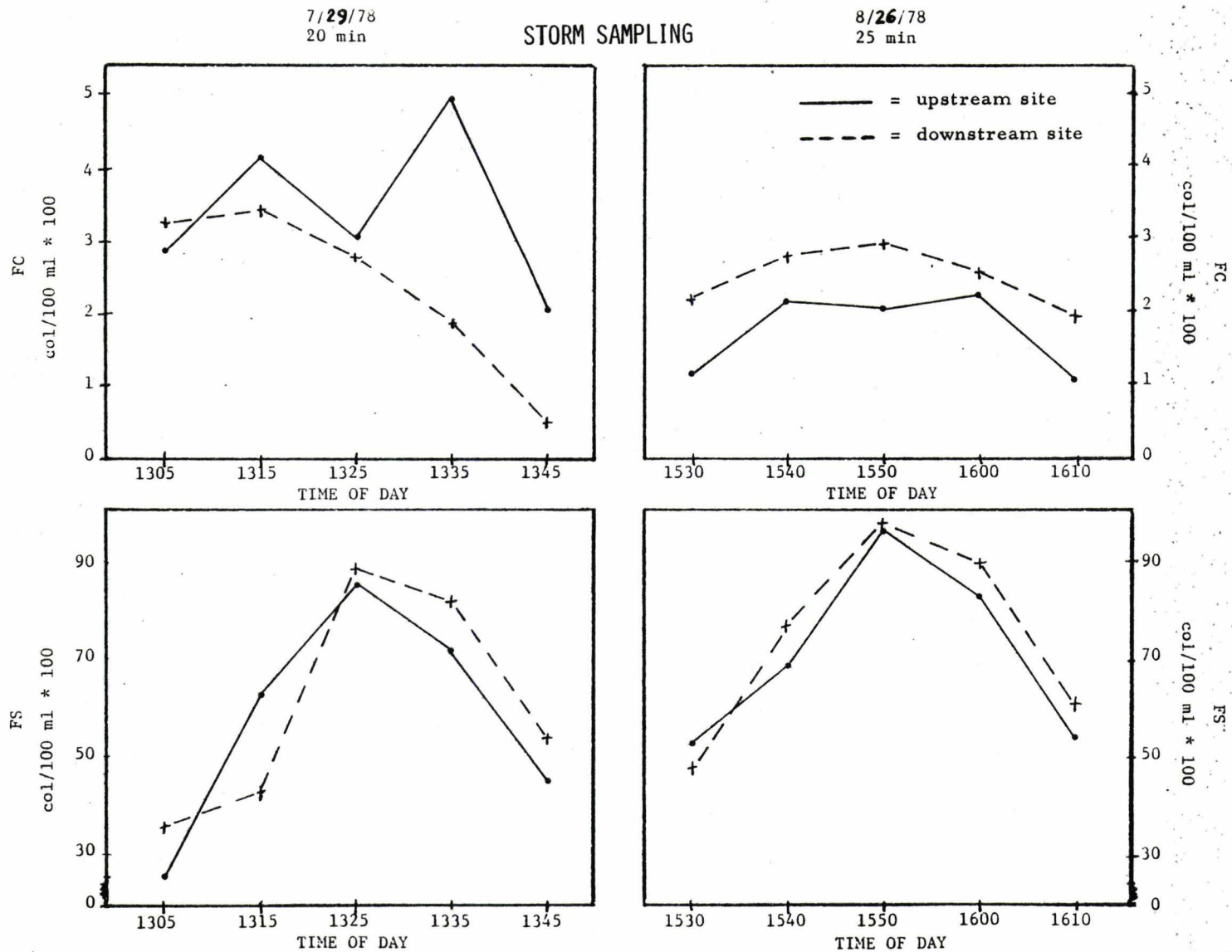


Figure 22. Storm concentrations of FC and FS at Treatment IV.

increase in counts for both sites may be attributable to the presence of livestock grazing and beaver within a half mile upstream from the treatment.

FC/FS Ratios

The following ratios of FC to FS were calculated from the results of the storm sampling.

Table 6. FC/FS ratios - storm sampling.

Storm	Treatment							
	I		II		III		IV	
I	U ¹	0.14	U	0.11	U	0.03	U	0.06
	D ²	0.11	D	0.09	D	0.05	D	0.04
II	U	--	U	--	U	0.03	U	0.02
	D	--	D	--	D	0.03	D	0.03

¹U denotes the upstream sampling site for a given treatment.

²D denotes the downstream sampling site for a given treatment.

All of the storm ratios were less than 0.7, which implied a greater influence upon the water quality from livestock and wildlife than from the developments. Because the ratios were very similar at both the upstream and downstream sites for all treatments, the sources of the increased bacteria probably originated upstream from the sampling sites.

CONCLUSIONS

Results of this investigation indicate that light residential and second home developments near Raymond, Allenspark and Estes Park, Colorado are not seriously affecting the water quality of nearby streams. None of the four treatment areas studied showed appreciable increases in suspended solids, primary nutrients or indicator bacteria between the two sampling sites during routine collection. Levels of significance for within and between treatment variation are summarized in Tables 7 and 8.

Even though suspended solids concentrations increased during stormflow, the increases were not attributable to poor road design. Most of the primary roads in the area had a vegetative buffer strip between them and the streams as well as stable, well vegetated side slopes and good drainage systems. Driveways were short and did not present a serious hazard to the streams.

Indicator bacteria counts, namely fecal coliform and fecal streptococci, also increased conspicuously during stormflow. However, the source of the fecal contamination does not appear to be derived from the developments since counts were similar at the upstream and downstream sites. FC/FS ratios indicate that the majority of the fecal contamination is from livestock and wildlife in the area.

Table 7. Significance levels for within treatment variation.

Year	Treatment	SS	NO ₃	PO ₄	Cl	FC	FS
1977	1	.05	---	---	---	---	---
	2	---	---	---	---	---	---
	3	---	---	---	.06	---	---
	4	.07	---	---	.01	---	.06
1978	1	---	---	.01	---	---	.10
	2	---	---	---	---	---	---
	3	---	---	.01	---	---	---
	4	.01	---	---	---	---	---

Table 8. Significance levels for between treatment variation.

Year	Treatment	SS	NO ₃	PO ₄	Cl	FC	FS
1977	1 vs. 2	---	---	---	---	---	---
	1 vs. 3	---	---	---	---	---	---
	3 vs. 4	---	---	---	---	---	---
	1,2,3 vs. 4	---	---	---	---	---	---
1978	1 vs. 2	---	---	---	---	---	---
	1 vs. 3	---	---	---	---	---	---
	3 vs. 4	.05	---	.05	---	---	---
	1,2,3 vs. 4	.01	---	.05	---	---	---

On the basis of the results obtained in this investigation, the following conclusions are drawn:

1. From day to day, second home developments appear to have little negative impact on stream water quality regardless of streamflow, housing density or sewage treatments studied.
2. Bacteriological ratios indicate livestock and wildlife have a greater impact on stream water quality than second home developments regardless of streamflow, housing density or sewage treatments studied.
3. Even though concentrations of suspended solids and indicator bacteria increase noticeably during stormflow, these increases appear to be channel derived and independent of the treatment areas examined.

Suggested Guidelines to Mountain Home Developers

To better protect stream water quality with respect to mountain home developments, the following guidelines are suggested:

1. Limit the proximity of the homes to the streams to 30 meters or more whenever feasible.
2. Utilize septic tanks for sewage disposal when possible and practicable. Placement should be as far away from the stream as topography and soil conditions permit. If there are inadequate or impermeable soils present, one modification which may be used is to provide additional soil for absorption of liquid wastes in a mound or fill system.
3. Road design should be pre-planned, including driveways. Road systems should avoid steep and unstable slopes. Stream crossings should be kept to the bare minimum. If finances permit, roads and driveways should be paved to help minimize sediment contributions to the stream.
4. Buffer strips along stream banks should be left in all instances.
5. Above all, pre-planning is essential. The developer should be aware of existing soil and hydrologic conditions, as well as limitations imposed by topography, well before the development construction is begun.

LITERATURE CITED

- American Public Health Association, Inc. 1971. Standard Methods for the Analysis of Water and Wastewater. 13th ed. Washington, D.C. 874p.
- Aukerman, Robert and William T. Springer. 1976. Effects of Recreation on Water Quality in Wildlands. Eisenhower Consortium for Western Environmental Forestry Research, Bulletin 2. USDA/FS. 25p.
- Baars, J. K. 1957. Travel of pollution and purification enroute in sandy soils. Bulletin World Health Organization 16:727-747.
- Baker, J. L., K. L. Campbell, H. P. Johnson, and J. J. Hanway. 1975. Nitrate, phosphorus and sulfate in subsurface drainage water. Journal Environmental Quality 4(3):400-412.
- Barton, M. 1951. A Progress Report on Suspended Sediment Sampling in Several Western Oregon and Western Washington Streams. Pacific N.W. Forest and Range Experiment Station. Note #75. 19p.
- Brickler, S. K. and J. G. Utter. 1975. Impact of recreation use and development on water quality in Arizona. Man, leisure, and wildlands: a complex interaction. Proceedings of the First Eisenhower Consortium Research Symposium. Rocky Mountain Forest and Range Experiment Station. pp. 195-201.
- Burns, L. K., D. R. McCrumb, and S. M. Morrison. 1973. Geologic Factors in the Evaluation of Water Pollution at Mountain Dwelling Sites. Environmental Resources Center, Completion Report Series No. 54, Colorado State University, Fort Collins, Colorado. 155p.
- Butler, R. G., G. T. Orlob, and L. H. McGaughey. 1954. Underground movement of bacterial and chemical pollutants. Journal American Water Works Assoc. 46:97-111.
- Cain, J. M. and M. T. Beatty. 1965. Disposal of septic tank effluent in soils. Journal Soil and Water Conservation 20:101-105.

- Dutka, B. J. 1973. Coliforms are an inadequate index of water quality. *Journal Environmental Health* 36:39-46.
- Flack, J. E. 1976. Design of Water and Wastewater Systems—for Rapid Growth Areas. Environmental Resources Center, Colorado State University, Fort Collins, Colorado. 138p.
- Franks, A. L. 1971. Practical geologic considerations for determining suitable locations for individual seepage disposal systems. Proceedings of the American Society of Civil Engineers, San Bernardino/Riverside, California. pp. 106-114.
- Geldreich, E. E. 1967. Fecal coliform concepts in stream pollution. *Journal Water and Sewage Works* 114:R-98-110.
- Geldreich, E. E., L. C. Best, B. A. Kenner, and D. J. Van Donsel. 1968. The bacteriological aspects of stormwater pollution. *Journal Water Pollution Control Federation* 40:1861-1872.
- Geldreich, E. E. and B. A. Kenner. 1969. Concepts of fecal streptococci in stream pollution. *Journal Water Pollution Control Federation* 41:R336-352.
- Grant, M. G. and W. M. Lewis, Jr. 1975. Nutrient Movement in a Mountain Watershed Supporting Light Residential Development, Progress Report, Eisenhower Consortium Project 16-529-CA. 6p.
- Hach Chemical Company. 1975. Hach Water and Wastewater. Analysis Procedure Manual. Hach Chemical Company, Ames, Iowa. pp. 2-77, 2-78.
- Hanway, J. J. and J. M. Laflen. 1974. Plant nutrient losses from trile-outlet terraces. *Journal Environmental Quality* 3:351-356.
- Howe, C. W. (Chairman). 1972. Residential Development in the Mountains of Colorado: A Handbook of Problems and Guidelines. Published by the United Banks of Colorado, Inc., Denver, Colorado. 106p.
- Johnson, B. A. and E. J. Middlebrooks. 1975. Water Quality as an Approach to Managing Recreational Use and Development on a Mountain Watershed. South Fork of the Ogden River - Ogden Valley Area, RRW A 21-1. Utah Water Research Lab, College of Engineering, Utah State University, Logan, Utah. 84p.

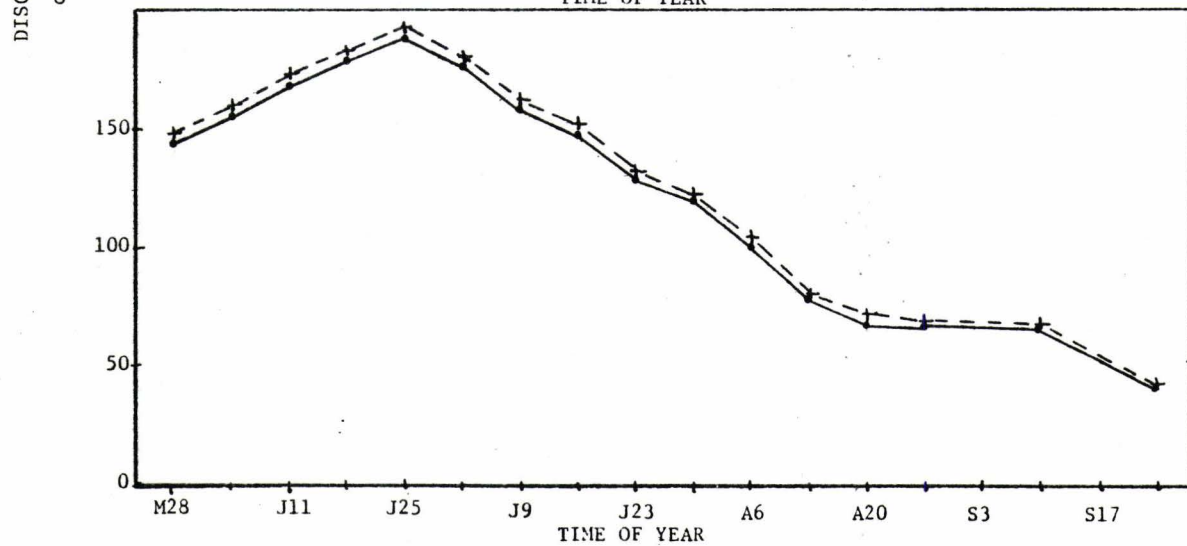
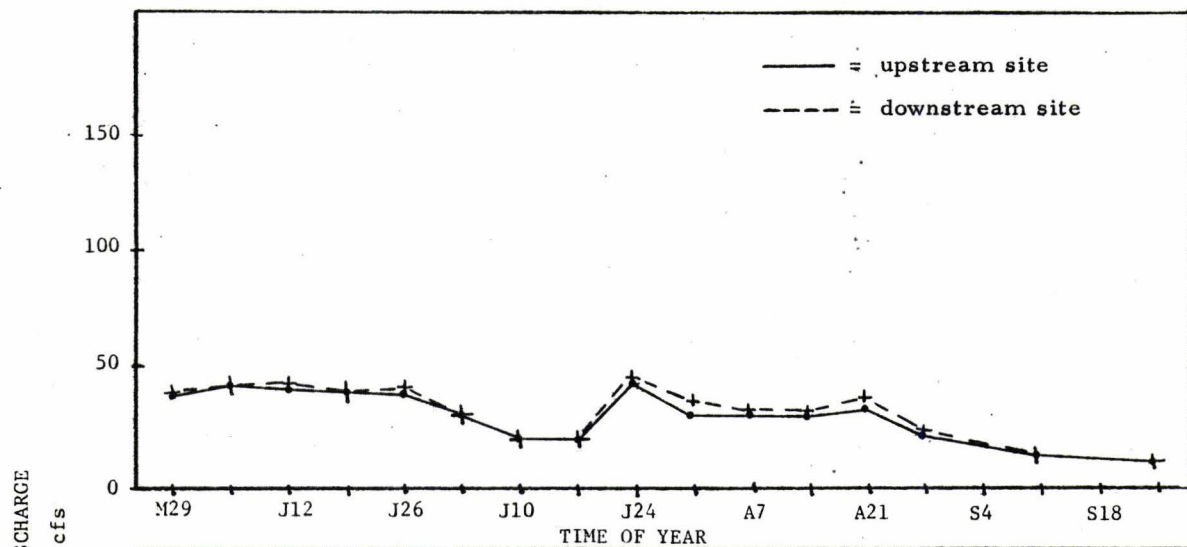
- Kittrell, F. W. and S. A. Furfari. 1963. Observations of coliform bacteria in streams. *Journal Water Pollution Control Federation* 35:1361-1384.
- Kunkle, S. H. 1965. A Review of Literature Relating to Water Quality in Mountain Watersheds, Cooperative Watershed Management Unit, Colorado State University, Fort Collins, Colorado. 33p.
- Kunkle, S. H. and J. R. Meiman. 1967. Water Quality of Mountain Watersheds, Hydrology Paper #21, Colorado State University, Fort Collins, Colorado. 53p.
- Kunkle, S. H. and J. R. Meiman. 1968. Sampling Bacteria in a Mountain Stream, Hydrology Paper #28, Colorado State University, Fort Collins, Colorado. 27p.
- McCarty, P. L. (Task Group Chairman). 1967. Sources of nitrogen and phosphorus in water supplies. *Journal American Water Works Association* 59(3):344-366.
- McFeters, G. A. and D. G. Stuart. 1972. Survival of coliform bacteria in natural waters: field and laboratory studies with membrane filter chambers. *Applied Microbiology* 24:805-811.
- Millipore Corporation. 1973. Biological Analysis of Water and Wastewater, Application Manual AM302, Millipore Corporation, Bedford, Massachusetts. 84p.
- Millon, E. R. 1970. Water Pollution, Red Feather Lakes Area, Colorado (Master's Thesis), Colorado State University, Fort Collins, Colorado. 68p.
- Morrison, S. M. and J. F. Fair. 1966. Influence of Environment on Stream Microbial Dynamics. Hydrology Paper #13, Colorado State University, Fort Collins, Colorado. pp. 1-2.
- Orlob, G. T. and R. B. Krone. 1956. Final Report on Movement of Coliform Bacteria Through Porous Media. Sanitary Engineering Research Laboratory, University of California. 46p.
- Petersen, N. J. and J. R. Boring, III. 1960. A study of coliform densities and Escherichia coli serotypes in two mountain streams. *American Journal Hygiene* 71:134-140.

- Ponce, S. L., H. L. Gary, and J.F.G. Bowlby. 1977. The Effect of Lake Based Recreation and Second Home Use on Surface Water Quality in the Manitou Experimental Forest, Colorado. Rocky Mountain Forest and Range Experiment Station. 33p.
- Romero, J. C. 1970. The movement of bacteria and viruses through porous media. *Groundwater* 8(2):37-48.
- Rudolfs, W., L. L. Falk, and R. A. Ragotzkie. 1950. Literature review on the occurrence and survival of enteric, pathogenic, and relative organisms in soil, water, sewage, and sludges, and on vegetation. *Bacterial and Virus Diseases, Sewage and Industrial Wastes* 22:1261-1281.
- Segall, B. A. 1975. The effect of second home and related vacation development use on water quality in Arizona. Man, leisure and wildlands: a complex interaction. Proceedings of the First Eisenhower Consortium Research Symposium. Rocky Mountain Forest and Range Experiment Station. pp. 221-226.
- Segall, B. A. 1976. The Impact of Vacation Homes on National Forest Water Resources. *Eisenhower Consortium Bulletin #3*. Rocky Mountain Forest and Range Experiment Station. 19p.
- Skinner, Q. D. et al. 1974. Effect of summer use of a mountain watershed on bacterial water quality. *Journal Environmental Quality* 3:329-335.
- Smith, M. E. 1975. Movement of Fecal Coliform Through Two Glacial Soils of Western Massachusetts (Master's Thesis). University of Massachusetts, Amherst, Massachusetts. 22p.
- Strickland and Parsons. 1968. A Practical Handbook of Seawater Analysis. University of California, Davis, California. pp. 49-52.
- Swenson, H. A. 1964. Sediment in Streams. *Journal Soil and Water Conservation*. 19:223-226.
- U.S. Environmental Protection Agency. 1973b. Processes, Procedures and Methods to Control Pollution Resulting from All Construction Activity. Office of Air and Water Programs, Washington, D.C. EPA-430/9-73/007. 234p.

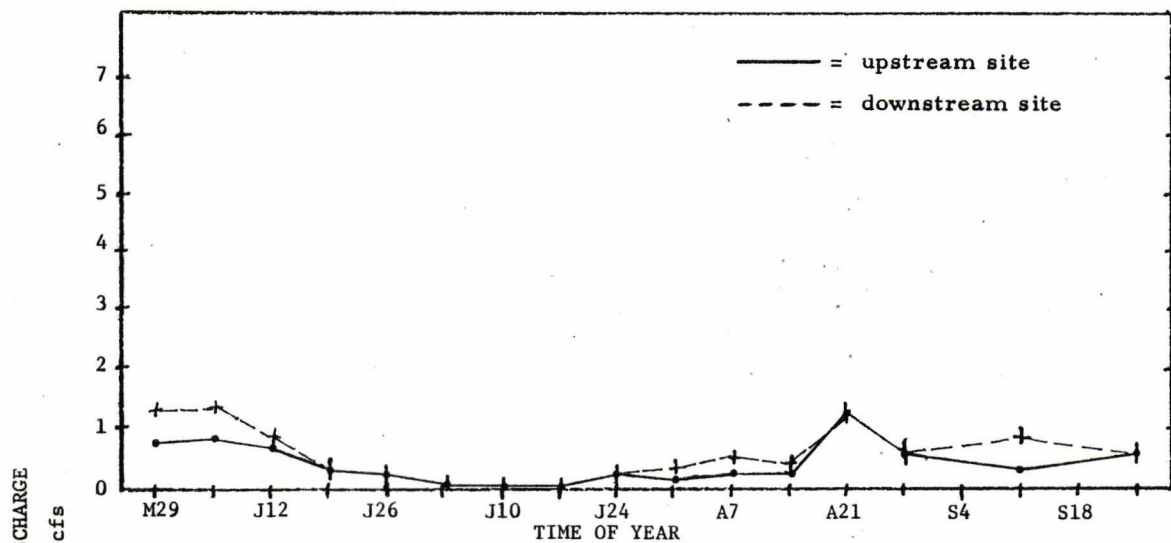
- Van Donsel, D. J., E. E. Geldreich, and N. A. Clarke. 1967. Seasonal variations in survival of indicator bacteria in soil and their contribution to storm-water pollution. *Applied Microbiology*.
- Vice, R. B., G. E. Ferguson, and H. P. Guy. 1968. Erosion from Suburban Highway Construction. Technical Note, Proceedings Paper #5742, Journal Hydraulics Division, American Society of Civil Engineers. pp. 345-348.
- Voelker, R. A., H. Heukelekian, and H. E. Orford. 1960. Seasonal coliform variations in well waters. *American Journal Preventive Medicine* 50(12):1873-1881.
- Walter, W. G. and R. P. Bottman. 1967. Microbiological and chemical studies of an opened and closed watershed. *Journal Environmental Health* 30:157-163.
- Worms, A. J. and S. K. Brickler. 1967. Effects of Recreation Use and Development on Water Quality. Cooperative Extension Service, Resource Development Series 12, University of Kentucky. 9p.

APPENDICES

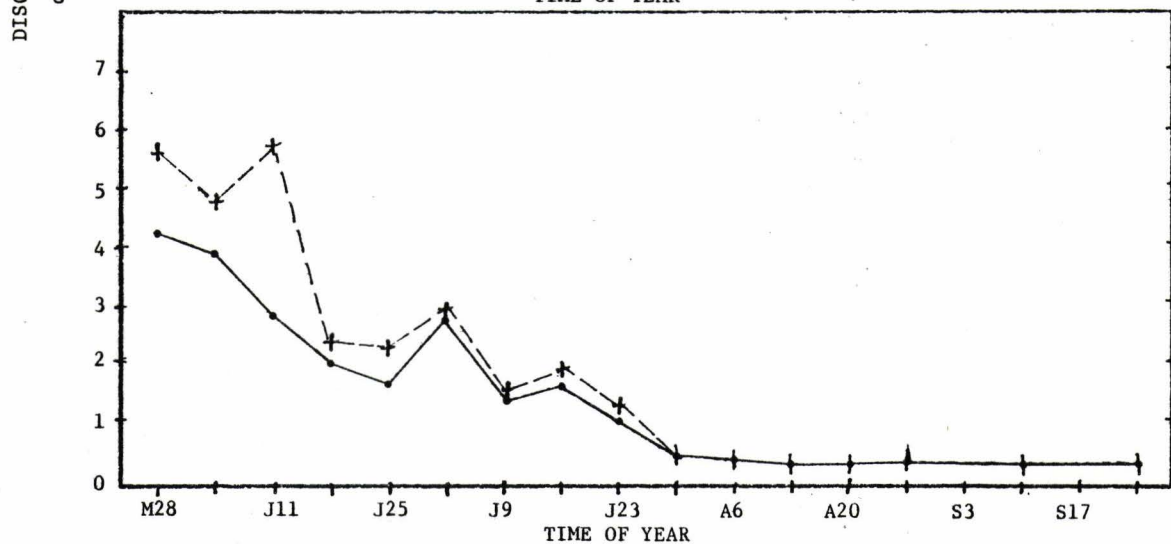
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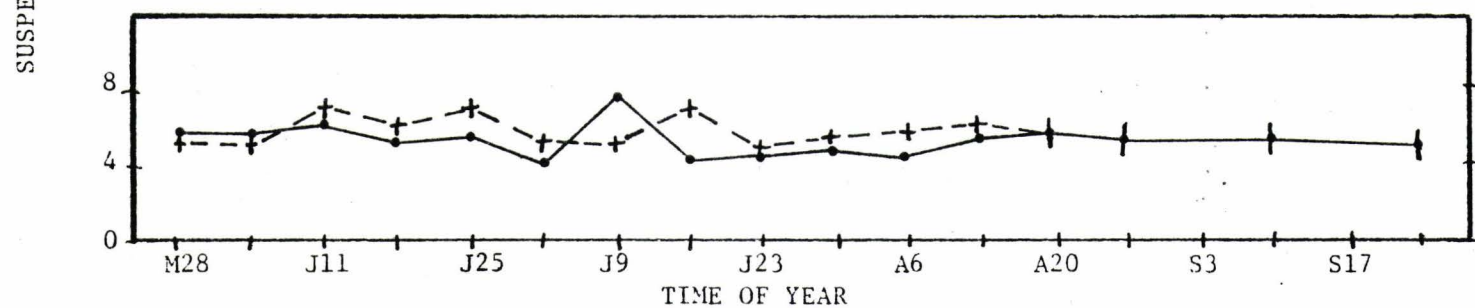
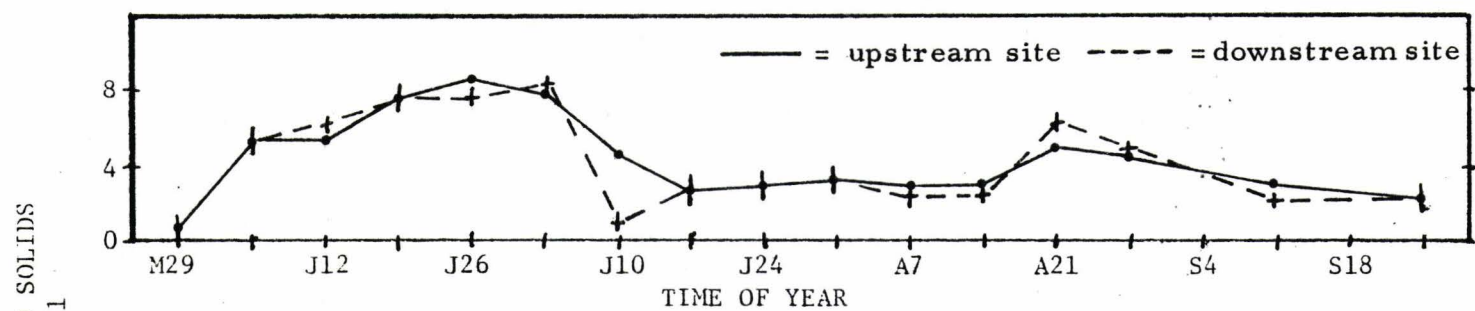


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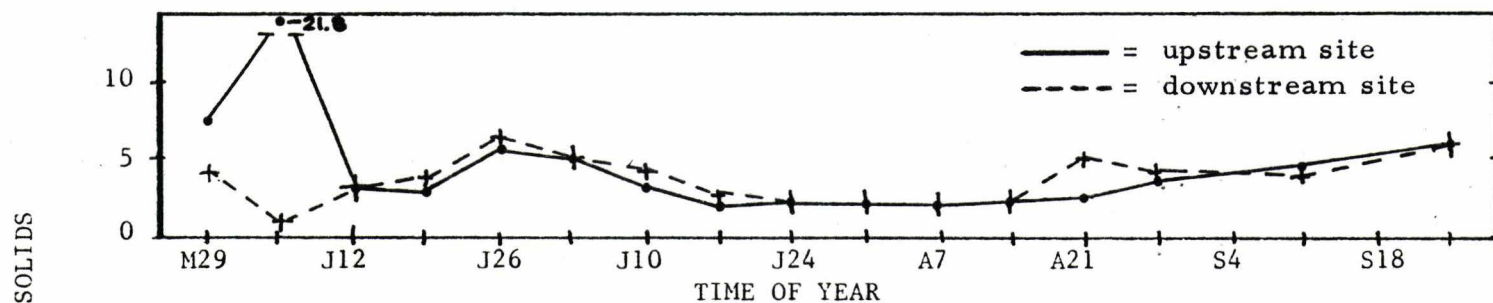


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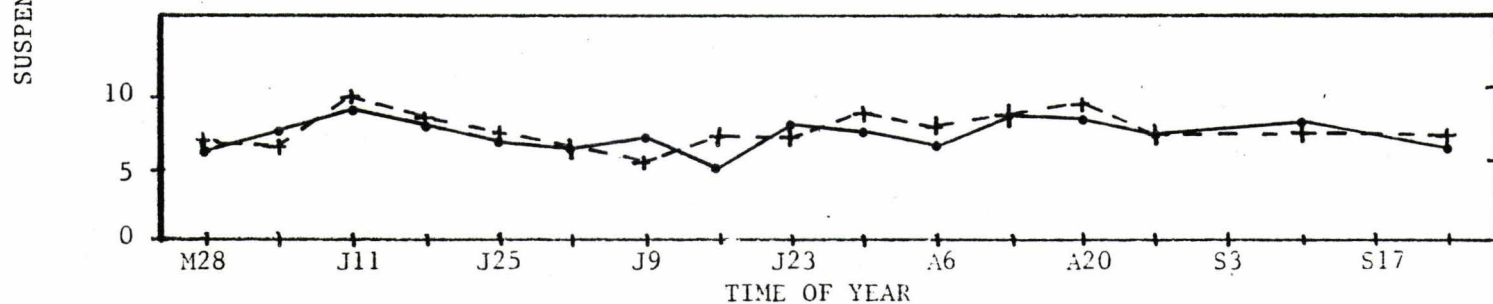
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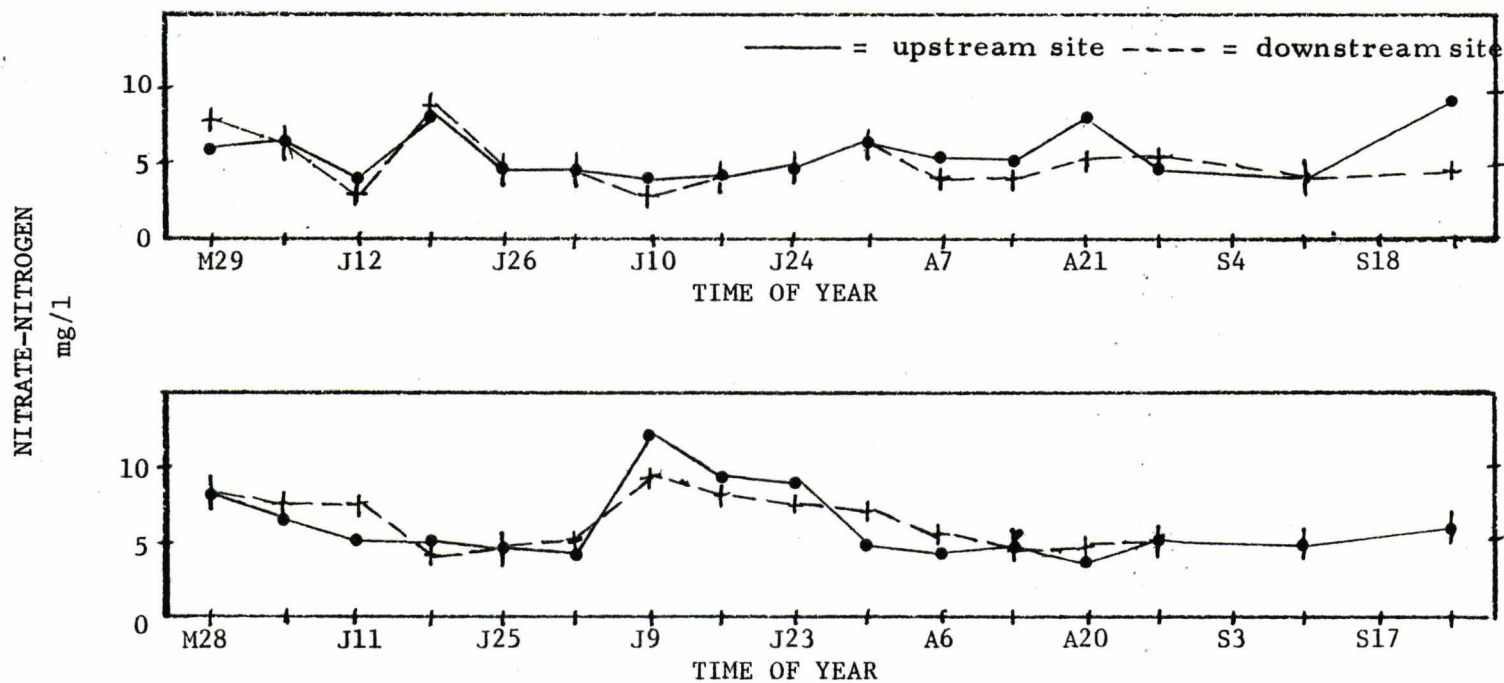


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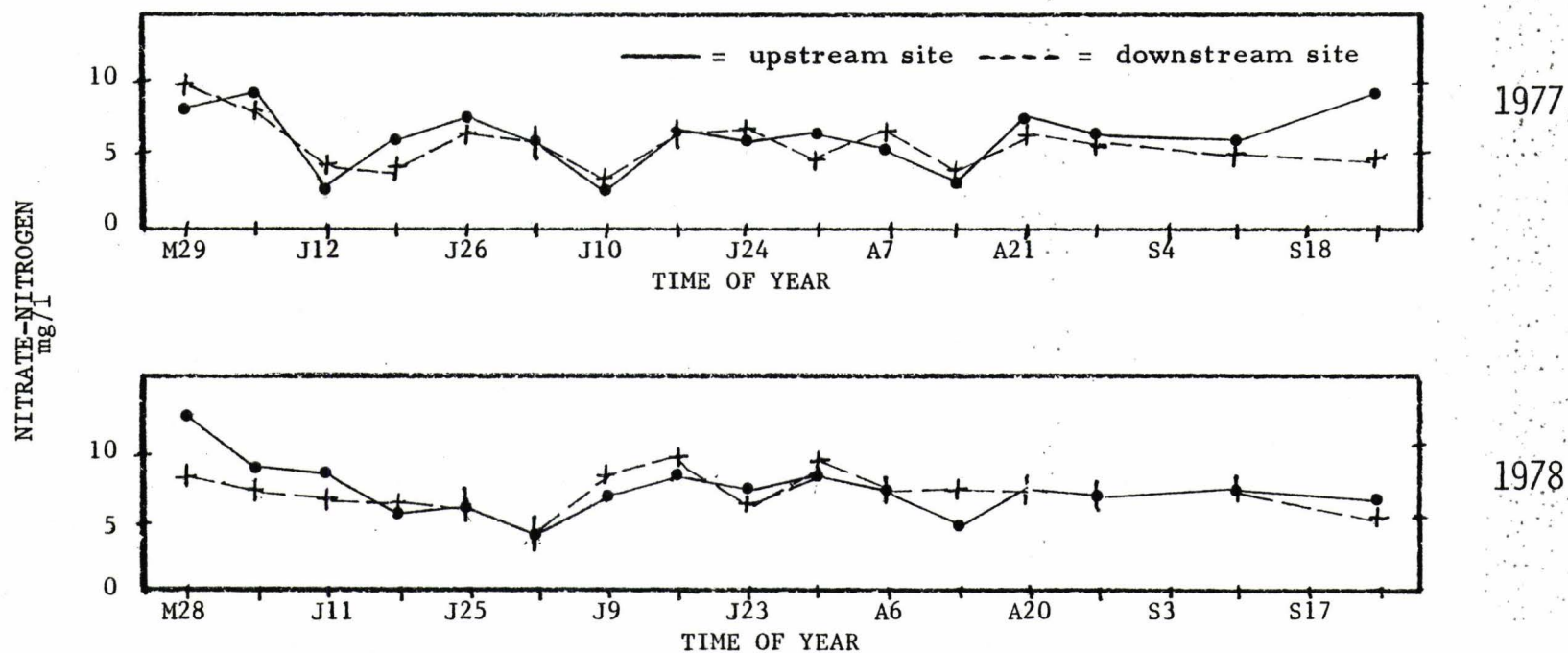


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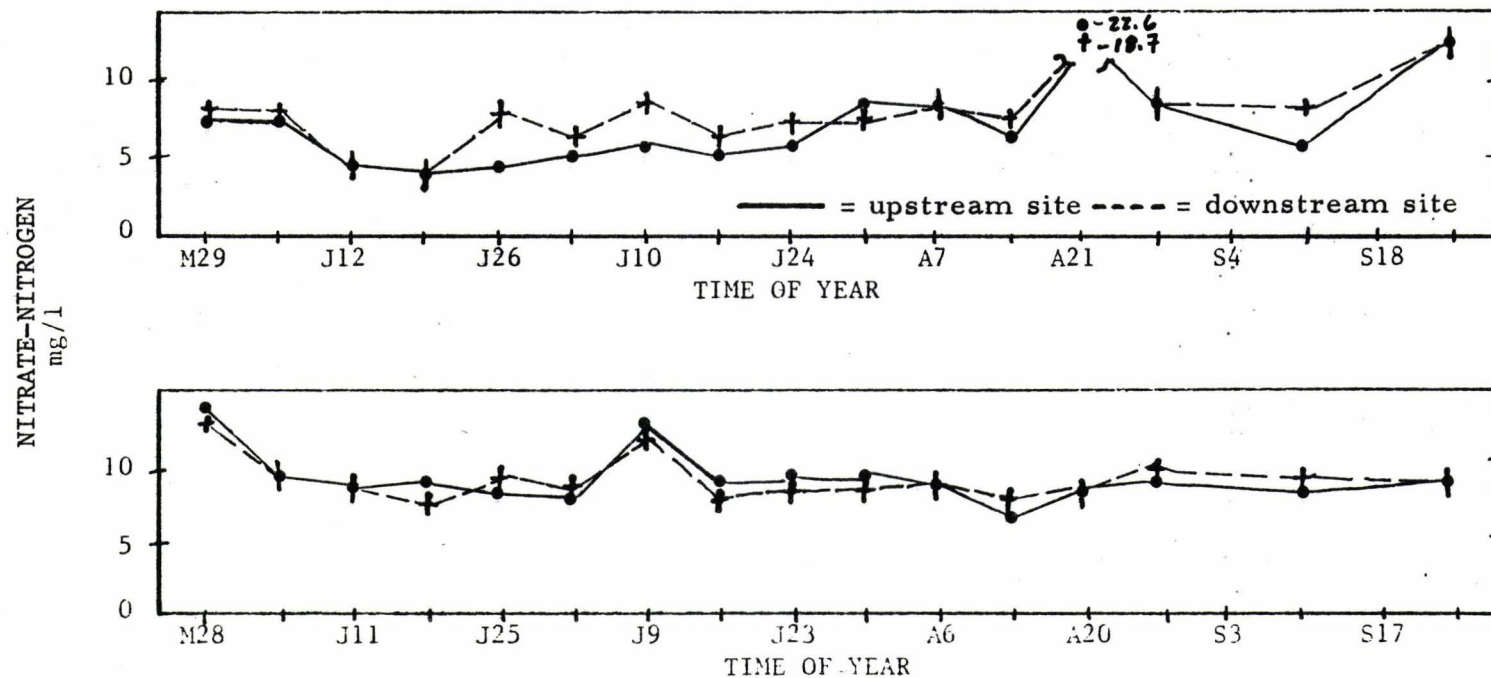
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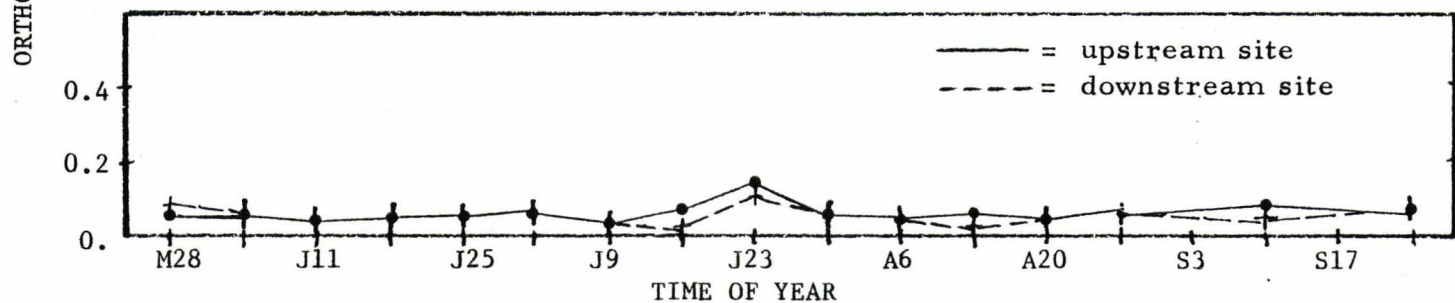
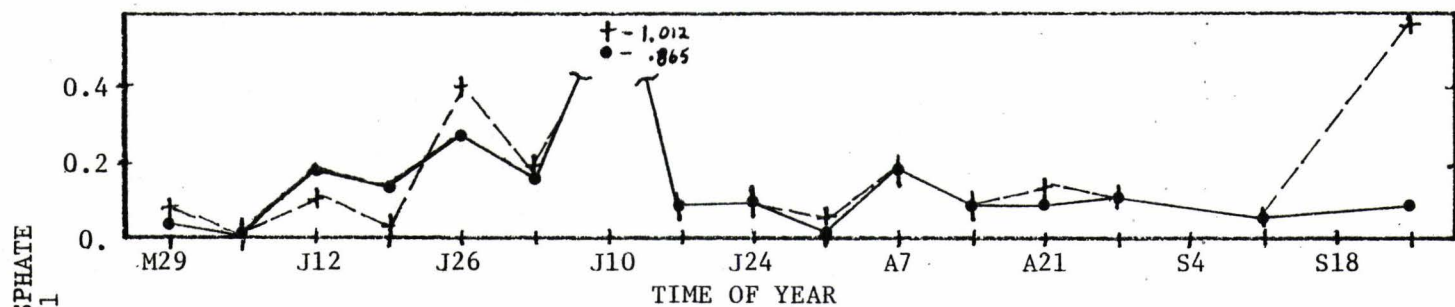
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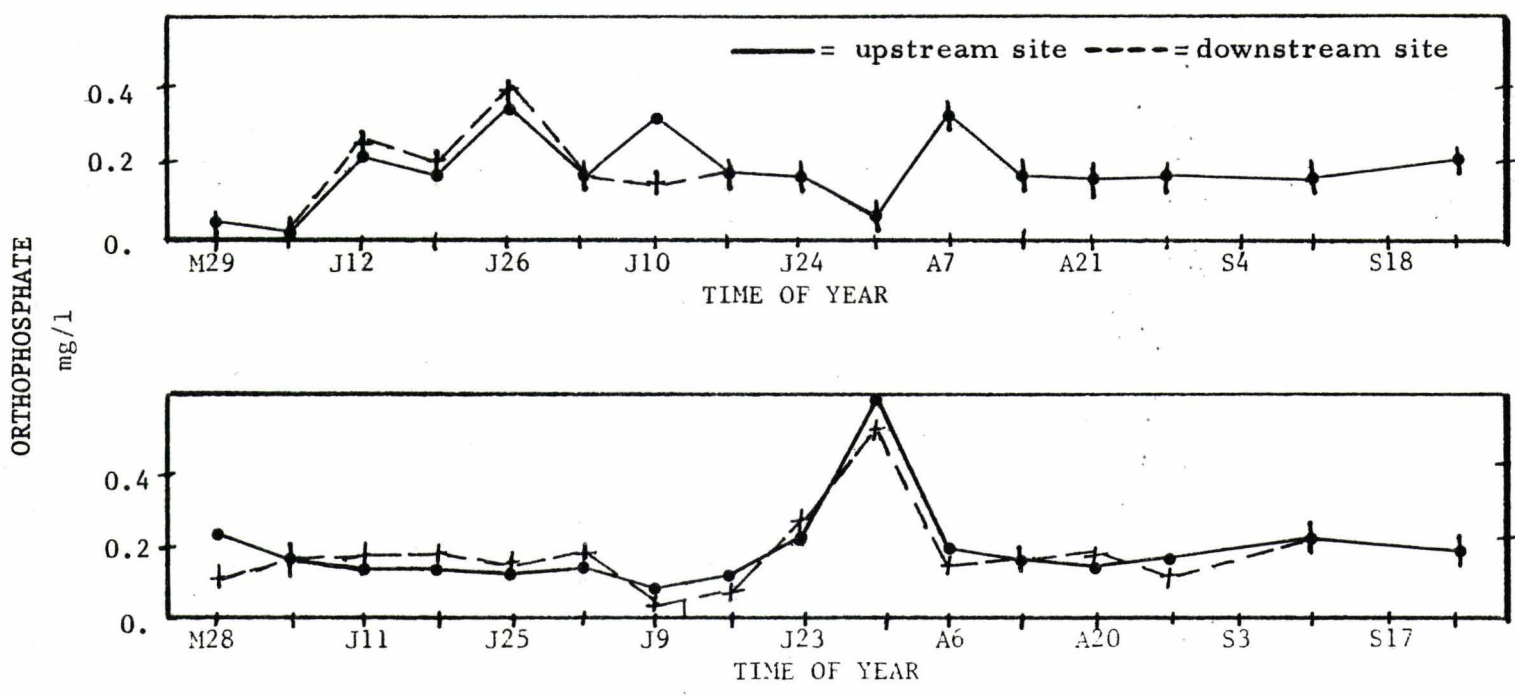
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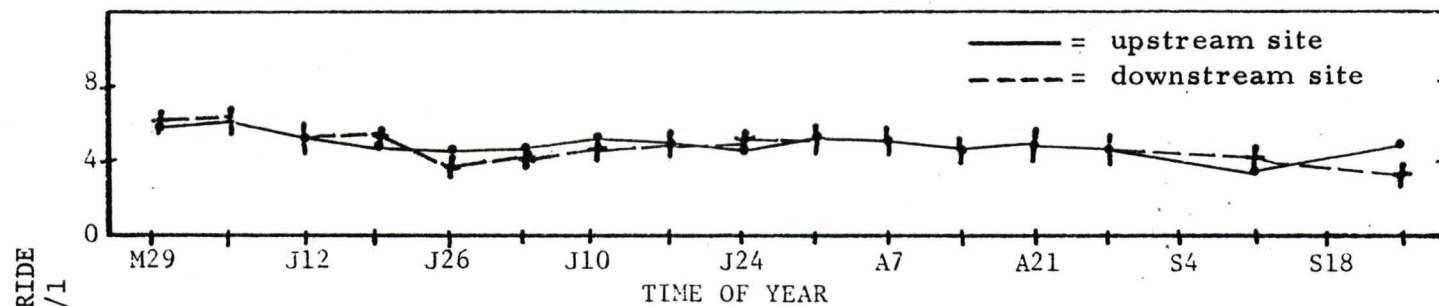
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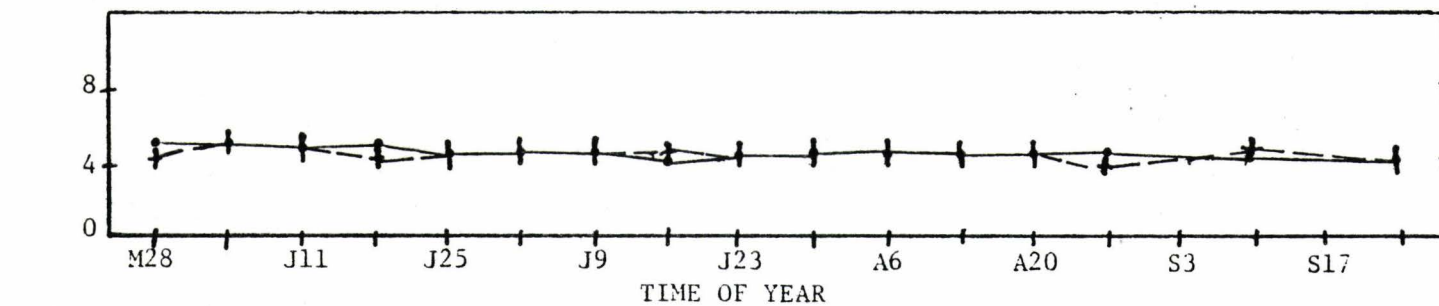
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